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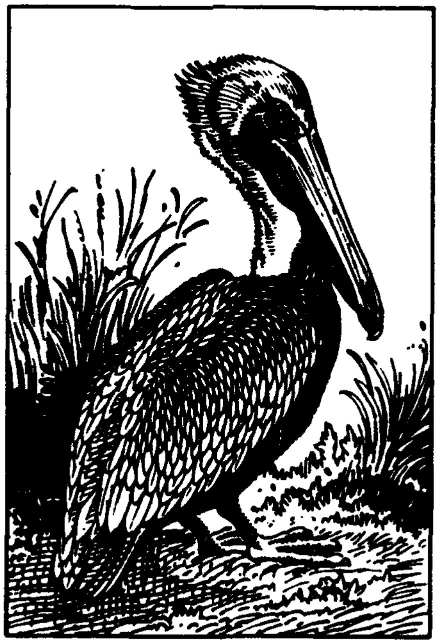
Wetlands Research Program Technical Report WRP-RE-3

Design of Habitat Restoration Using Dredged Material at Bodkin Island, Chesapeake Bay, Maryland

by Stephen T. Maynord, Mary C. Landin, John W. McCormick,
Jack E. Davis, Robert A. Evans, Donald F. Hayes



June 1992 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Corps of Engineers Research Report Summary, June 1992

Black Duck Habitat

Design of Habitat Restoration Using Dredged Material at Bodkin Island, Chesapeake Bay, Maryland (TR WRP-RE-3)

ISSUE:

The Black Duck population in the Chesapeake Bay area is threatened due to loss of nesting and brood habits, much of which can be attributed to wind wave induced erosion.

Bodkin Island provides excellent Black Duck nesting habitat, but erosion has reduced the size of the island from 50 acres in 1847 to its current 0.94 acres. Presently, the island has no brood habitat, and hatchlings of Bodkin Island are subject to high mortality as they seek distant habitats.

RESEARCH:

Primary objectives were

- reestablishment of Black Duck brood habitat
- improvement and additions to nesting habitat, and
- overall island stability.

The research resulted in a design for the enlarged Bodkin Island that includes shoreline stability, hydrodynamic impacts, habitat shaping, and vegetation that provides a combination of upland nesting, intertidal marsh, and tidal pool habitat.

SUMMARY:

Dredged material will be used to restore the island to 4.8 acres around the existing island. Nesting and brood habitat for the Black Duck population will be reestablished.

AVAILABILITY OF REPORT:

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About the Authors:

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Contents

Preface

The Bodkin Island wetland restoration design study was authorized and funded by the US Army Engineer District, Baltimore (NAB). The study was conducted by the personnel of the Hydraulics Laboratory (HL), the Environmental Laboratory (EL), and the Coastal Engineering Research Center (CERC), all of the US Army Engineer Waterways Experiment Station (WES), during the period March through June 1991. The final report was written by Dr. Stephen T. Maynord, HL; Dr. Mary C. Landin, EL; Messrs. John W. McCormick and Jack E. Davis, CERC; Mr. Robert A. Evans, HL; and Dr. Donald F. Hayes, EL.

The Bodkin Island wetland site was a demonstration site under Task Area V of the US Army Corps of Engineers Wetlands Research Program (WRP), Wetlands Restoration, Protection, and Establishment, and was part of Research Area 3, Coastal Shoreline and Channel Protection, under Work Unit 32761, Wetlands Field Demonstrations. Dr. Maynord and Mr. Davis were co-Principal Investigators of Research Area 3; Dr. Landin was Principal Investigator of Work Unit 32761 and Manager of Task Area V. Overall WRP manager was Dr. Russell F. Theriot, EL.

Project Manager at NAB was Mr. Robert N. Blama, Operations Division, NAB. The design study was coordinated with NAB; Mr. John Gill, US Fish and Wildlife Service, Annapolis, MD; and Mr. W. R. Carter, III, and Mr. Jonathan McKnight, Maryland Department of Natural Resources, Annapolis, MD. Inter-agency input was also sought from the US Environmental Protection Agency and the NOAA National Marine Fisheries Service.

The report progressed under the general supervision of three WES laboratories. Dr. Maynord worked under the general supervision of Mr. Frank A. Herrmann, Jr., Director, HL; Mr. Glenn A. Pickering, Chief of the Hydraulics Structures Division (HSD), HL; and Mr. Noel R. Oswalt, Chief, Spillways and Channels Branch, HSD. Dr. Landin worked under the general supervision of Dr. John Harrison, Director, EL; Dr. Conrad J. Kirby, Chief, Environmental Resources Division (ERD), EL; and Mr. E. C. Brown, Chief, Wetlands and Terrestrial Habitat Group, ERD. Messrs. McCormick and Davis worked under the general supervision of Dr. James R. Houston, Director, CERC; Mr. Thomas W. Richardson, Chief, Engineering Development Division (EDD), CERC;

Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch, EDD; and Dr. Yen-Hsi Chu, Chief, Engineering Applications Unit, EDD. Mr. Evans worked under the general supervision of Mr. Herrmann; Mr. William H. McAnally, Jr., Chief, Estuaries Division (HED), HL; and Mr. David R. Richards, Chief, Estuarine Simulation Branch, HED. Dr. Hayes worked under the general supervision of Dr. Harrison; Dr. Raymond L. Montgomery, Chief, Environmental Engineer Division (EED), EL; and Dr. John J. Ingram, Chief, Water Resources Engineering Group, EED.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square.metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
degree (angle)	0.01745329	radians
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square yards	0.8361274	square metres
tons (long mass)	1,016.647	kilograms

1 Introduction

Background

Wind wave induced erosion has resulted in significant loss of black duck (*Anas rubripes*) habitat in the Eastern Bay of Chesapeake Bay. A prime example of habitat loss is Bodkin Island located as shown in Figure 1. Wind wave erosion separated Bodkin Island from the mainland in the late 18th/early 19th century (Cronin 1986). A 1847 topographic map shows a remaining island area of 50 acres.[1] Deed records in 1864 record a surveyed area of 40 acres. In 1899, Bodkin Island had eroded to 32 acres. In 1953, Bodkin Island consisted of two islands totalling 4.8 acres (V. D. Stotts letter, 1991, see Carter 1991). In 1984, a wooden bulkhead surrounding the entire island was completed by the island owner, leaving the island fixed at the present 0.94 acres (Figure 2). Riprap was placed adjacent to the bulkhead to provide additional protection after portions of the bulkhead failed (Figure 3).

Bodkin Island provides excellent black duck nesting habitat. In 1954, Stotts found 106 nests on the 4.8-acre island (Stotts and Davis 1960). In 1986, after its size was fixed with perimeter bulkheading at 0.94 acres, about 50 percent of the number of 1,954 nests were found (Stotts 1987). Kirby (1988) indicated that Bodkin Island maintained a nesting density 19 times greater than the next two highest black duck production areas in North America. According to Stotts, a 1987 fire initially reduced black duck use on Bodkin Island, but the population is now recovering. A 1991 survey by Stotts found 34 active black duck nests in habitats on the island (Figure 4).[2]

At the same time Bodkin Island was eroding, nearby shoreline marshes were also eroding. This erosion has resulted in a current condition of no

[1] A table of factors for converting non-SI units of measurement to SI units is found on page vii.

[2] Personal Communication, June 1991. John Gill, US Fish and Wildlife Service, Washington, DC.

brood habitat within several miles of the island. Hens with newly-hatched ducklings must leave the island to find food and swim long distances, resulting in extremely high mortality of hatchlings. Shoreline development is of equal consequence to success of brood rearing. Isolation during nesting and brood rearing is a paramount requirement for black duck hens.

Objective and Approach

The primary objectives of Bodkin Island restoration, therefore, are (a) reestablishment of brood habitat, (b) improvement and additions to nesting habitat, and (c) overall island stability. The habitat restoration at Bodkin Island will use 45,000 cu yd of fine sand from the October 1991 maintenance dredging of the Long Point/Kent Narrows approach channel in the Chester River. The dredged material will be pumped to and placed adjacent to the existing Bodkin Island on its north/northwest side. The dredged material will then be shaped, stabilized, and vegetated to restore suitable black duck nesting and brood habitat. This project is a cooperative effort of the State of Maryland, the US Fish and Wildlife Service (FWS), and US Army Corps of Engineers (USACE). The State of Maryland is the local project sponsor. Funding will be provided by the State of Maryland and the US Army Engineer District, Baltimore (NAB), under Section 1135 of the Water Resources Development Act of 1986 (authorized in 1986 - not funded by Congress until 1991), and logistical and labor support will be provided by the FWS and Maryland Department of Natural Resources (MDNR). The State of Maryland is acquiring the island from the private landowner.

This report provides a design for the enlarged Bodkin Island that includes shoreline stability, hydrodynamic impacts, habitat shaping, and vegetation that provide a combination of upland nesting, intertidal marsh, and tidal pool habitat. The project design reported herein is a joint effort of the Hydraulics Laboratory (HL), the Environmental Laboratory (EL), and the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES).

Existing Conditions

Bathymetric data showing water depth below mean low water (MLW) around Bodkin Island were collected by NAB and are shown in Figure 5. Tidal data in feet at Bloody Point Bar Light (6.3 miles SW of Bodkin Island) relative to MLW are in the following table. Data were taken from NOAA chart for Chesapeake Bay, Eastern Bay, and South River. Tide tables show a spring tide range of 1.3 ft.

Mean High Water	1.1	Astronomical
Mean Tide Level	0.5	Astronomical
Mean Low Water	0.0	Astronomical
Extreme Low Water	-4.0	Wind induced

2 Orientation and Shape of the Enlarged Island

The location of dredged material to be placed relative to the existing island depends on several factors. Of primary concern is the disturbance of the razor clam population near the island. An evaluation of the clam resources near Bodkin Island was conducted by W. R. Carter III, MDNR, in April 1991 (see Carter 1991). Based on this evaluation, the dredged material should be placed northwest of the existing island. Also to be considered in determining the location of the dredged material placement is the need to place the material on the shallowest part of the bay so as to maximize the area of the completed project. The shallowest part of the bay around Bodkin Island is located north of the existing island. A schematic of the proposed habitat restoration is shown in Figures 6 and 7, with the dredged material centered north/northwest of the existing island. Volume of dredged material required is 38,400 cu yd which is less than the estimate of the quantity available from the maintenance dredging. This amount will allow for some loss during construction, and any excess can be placed on the existing island to restore areas that have been eroded. Any future additions could be placed northwest, north, or northeast of the initial addition and connected to the opening on the north side of the island.

The shape of the proposed project is circular because this shape minimizes the amount of riprap required for a given area and is the most efficient and cost-effective engineering design. The circular shape also eliminates any sharp corners, which tend to be weak spots when subjected to wave activity.

The existing bulkhead will be left intact. Dredged material or rock spalls will have to be placed on the southwest, south, and southeast sides of the existing island to bring the top elevation of the protection up to design elevation (el) of 6.5 ft MLW. Existing riprap placed by the current landowner next to the south and southwest bulkheads will remain and additional riprap will be placed up to el 6.5.

3 Island Construction and Material Quantities

Phased construction is recommended for the enlargement of Bodkin Island to protect against material loss during placement and ensure proper final elevations. The phasing should consist of (a) placement of containment dike, (b) placement of armor stone, (c) placement of dredged material, and (d) reshaping material to form final island shape. These phases are described in detail below.

Placement of Containment Dike

Dredged material from the Long Point/Kent Narrows approach channel planned for use in enlarging Bodkin Island is anticipated to be primarily fine sands. Current plans call for hydraulic dredging of the approach channel and using booster pumps to move the material over the 5-mile distance to Bodkin Island. Unconfined hydraulic placement of this material in a high energy environment such as exists around Bodkin Island may result in a significant loss of material. Since the project requires careful utilization of the 45,000 cu yd available to accomplish its objectives, confinement is required to minimize material loss.

To provide the confinement or protection needed during the dredged material placement, rock spall dikes should be placed along the exterior boundary of the proposed upland areas to form the containment structure as shown in Figure 8. A 50-ft-wide notch at el 3.0 on the north end of the containment dike would provide a release point for the effluent from the dredged material.

Placement of Armor Stone

Once the containment dike is complete, armor stone can be placed to prevent loss of the containment dike in the event of a major storm. Armor stone placement on the north facing opening would have to wait until the dredged material is placed and shaped. Alternately, the armor stone placement could follow or be concurrent with placement of the dredged material. To prevent dredging of an access channel, armor stone should be transported by partially loaded barges under high-tide conditions.

Placement of Dredged Material

Dredged material placement should be directed to best fit the proposed habitat restoration (Figure 7). This phase would consist primarily of placing the dredged material against the containment dike as much as possible to form the upland areas.

Island Shaping

Once dredged material placement is complete, earthmoving equipment such as dozers, draglines, and backhoes outfitted with low-pressure tracks will be necessary to shape the dredged material into the desired final configuration for habitat restoration. Sediment should be removed from the center of the site and used to bring the upland nesting dikes to el +10.0 MLW.

Once exterior dikes and the placement of dredged material are complete, the interior area should be reshaped to form the ponds and channels according to the elevations specified in Figure 7. Interior dike slopes can be flattened and/or crest widths increased to hold more material if excess material is available. In the event of too little dredged material, the crest width can be decreased to a minimum width of 20 ft. It may be desirable not to open the containment dike to the bay until all features are in place (tidal ponds, tidal channels, and riprap at entrance of island) prior to planting the island.

4 Habitat Restoration Features

Habitat requirements of black ducks are well-documented (Stotts and Davis 1960, Johnsgard 1975, Bellrose 1976, Kirby 1988), and site-specific requirements pertaining to Bodkin Island have been reported by Stotts and Gill in personal communications. The restoration plan for Bodkin Island includes a combination of upland nesting areas in conjunction with the existing island. An upland/high marsh/low marsh gradation will also be included from the island crest down to tidal pools that will provide shallow water for use by black duck hens and broods of ducklings. The resulting habitat diversity will provide maximum improvement to the existing black duck habitat, using all of the available dredged material. The island will provide 3.57 acres of new nesting and feeding habitat, plus 1.02 acres of new riprapped slopes (Figure 9).

The island has been designed with 1V:2H outer slopes and 1V:6H interior slopes from the upland crest down to the tidal pools. Tidal pools are designed at a 1V:20H bottom slope to provide a broad range of water depths and maximum habitat values. These slopes are feasible from an engineering standpoint; however, a primary reason is that gentle interior slopes from the nesting areas down to the tidal pools are more suitable for hens and hatchlings trying to reach shallow water. Since mean high water (MHW) at Bodkin Island averages +1.1 ft, slopes and gradations are critical to plant survival and colonization. Habitat zones are shown in Figure 10. Tidal pools will be excavated to -3.0 ft MLW, with -1.0 ft MLW tidal creeks providing intertidal exchange. The exchange will provide for 18 to 24 in. of water in the ponds, and not more than 3.5 ft inside the island ponds at MHW. The ponds are expected to reach a depth of 2.0-2.5 ft over time as they develop and intertidal exchange provides bay sediments. The low marsh zone will grade from -1.0 to +1.0 ft MLW, and the high marsh zone will grade from +1.0 to +4.0 ft. The nesting area will be comprised of the upper slope and crest (+4.0 to +10.0 ft). The areas between the tidal pools will include small tidal channels to provide greater surface to water interface to allow for greater production of invertebrates. These areas will be kept at the low marsh zone elevation (0.0 to +1.0 ft) to provide for more marsh vegetation and plant cover.

With the exception of the crest of the existing island, the riprap face, and the tidal pools, the entire island will be planted with selected vegetation that provides good nesting and brood cover as well as some food material. Growing ducklings eat large numbers of aquatic invertebrates, with increasing amounts of plant food items as they mature. Tidal pools and connecting tidal creeks are designed to provide a stable water level of approximately 18 to 24 in. MLW, optimum depths for abundant invertebrate populations and feeding black ducks. The existing island's crest vegetation will be left intact, in spite of relatively undesirable plants currently growing on it. The purpose is to ensure continuity of some nesting habitat while the new portions of the island are being constructed and vegetated. Once the island vegetation has established, existing exotic plants such as multiflora rose (*Rosa* sp.) and broom sedge (*Andropogon* sp.) on the island crest can be removed or killed. It should be noted that a number of songbirds species such as northern cardinals (*Richmondena cardinalis*) and mourning doves (*Zenaidura macroura*) also nest on this island; their habitats will also be enhanced and expanded as a result of habitat restoration for black ducks.

The design plan also includes the installation of four osprey nest platforms of varying heights on island perimeters to encourage nesting by ospreys. Ospreys (*Pandion haliaetus*) are exclusively fish-eaters and are compatible with nesting black ducks. Their presence tends to discourage aerial predators such as herring gulls (*Larus argentatus*) and fish crows (*Corvus ossifragus*) which will prey on eggs and young ducklings. The osprey nest currently on the island is constructed in the only remaining tree on the island, a tall, dead pine snag (Figure 2). Platforms will ensure that ospreys continue to occupy the island after the dead pine falls.

An additional habitat benefit will be derived from the protection provided by the entire island to surrounding areas, especially to the north. This shallow area already has a small population of razor clams (*Tagelus plebeius*) due to the existing island's breakwater effect. Potential for marine habitat will be greatly enhanced by the size and location of the new island.

Monitoring of the Bodkin Island restoration will be necessary to determine success of the project. A monitoring plan and time frame will be developed prior to project construction through mutual agreement among cooperating agencies that will include both engineering and environmental parameters. Monitoring will be conducted by WES, the Annapolis office-FWS, and Mr. Vernon D. Stotts (MDNR Waterfowl Biologist, retired). This monitoring plan includes actual placement of dredged material and all construction and habitat development, and actual habitat use and successional progress on the island by black ducks, ospreys, and other biota.

5 Stability of Habitat Features From Tidal Flows

Tidal inlets are often subject to erosion and/or deposition problems due to tidal flows and longshore transport. Bathymetric data show no indications of deposition near the existing Bodkin Island, and the completely riprapped island will not have significant longshore transport past the inlet. However, wave activity and tidal currents in the shallow areas at Bodkin will result in material transport (particularly silts and clays), some of which will find its way into the inlet. The amount of material deposited in the inlet should be maintainable, and the primary stability concern for the island's interior is to size the tidal creeks large enough to prevent erosion from the maximum tidal flows that would occur during spring and storm tidal conditions. The size of the tidal creeks will decrease as deposition occurs, until an equilibrium cross section is achieved. A spring tide from 0.5 to 1.8 ft MLW was selected for use in evaluating the stability of the island interior. A schematic of the tide range relative to the tidal creek bottom and the low marsh area is given in Figure 11. The resulting tidal prism volume, P, above the entrance to the bay is 89,000 cu ft. Based on Keulegan (1967), the maximum discharge Q_m over the tidal cycle is

$$\frac{T Q_m}{\pi P} = C \qquad (1)$$

where C is approximately 1 and used conservatively herein equal to 1, and T is the tide period in seconds. The resulting Q_m is 6.5 cfs. This relatively low flow is consistent with the relatively low-tide range present at Bodkin Island and the small area of the island. O'Brien (1976) reported on empirical relations for the minimum stable channel area, A_c, required below the mean water elevation which in this case would be (0.5 + 1.8)/2 = 1.15 above MLW as shown in Figure 11. O'Brien addressed coastal inlets having significant wave/littoral transport at the inlet. While Bodkin Island is not expected to have significant littoral transport, O'Brien's work presents the most applicable techniques short of a physical or numerical modeling effort. O'Brien (1976) references Johnson (1973) who found

$$\frac{P^{0.85}}{A_c} = 2,400 \tag{2}$$

where the tidal prism volume is in cubic feet and A_c is in square feet. The tidal prism volumes used in determining Equation 2 were all greater than P at Bodkin Island. However, O'Brien showed that an almost identical equation can be derived from Lacey's (1929) regime equations which adds support to the use of Equation 2. The resulting channel area below the average water level of 1.15 ft MLW is 6.7 sq ft. Channel width will be determined assuming the 1.0-ft-MLW marsh area is densely vegetated and all flow is in the tidal creek. With the tidal creek bottom fixed at -1 ft MLW, the water depth is 2.15 ft. The required minimum average width will be 6.7/2.15 = 3.1 ft. The maximum average channel velocity will be 6.5/6.7 = 0.97 ft/sec, which should be stable for the fine sand dredge material used to construct Bodkin Island. As stated above, deposition problems that are not maintainable are not anticipated. Consequently, the minimum channel area determined above can be increased to ensure that channel cross sections remain stable when tidal ranges exceed the spring tidal range of 1.3 ft because of wind setup or other factors. A cross section having 6-ft-bottom width and 1V:3H side slopes is recommended. The resulting maximum average channel velocity at the mouth of the tidal creek for the spring tide is 0.3 ft/sec. These tidal creeks will undergo deposition until a stable or equilibrium cross section is reached.

As shown in Figure 9, the junction of the tidal creek with the bay is stabilized with riprap to ensure that the tidal creek remains stable when extreme low tides occur in the bay.

6 Wave and Storm Surge Analysis and Revetment Design

Introduction

Bodkin Island's historic exposure to significant wave attack from several directions has nearly eliminated the island. Prior to application of its existing protection, the island was apparently eroded by direct storm wave attack and related overtopping. The existing protection (bulkheads and riprap) affords some measure of protection against small waves, but the island is still exposed to larger waves especially when Eastern Bay water levels are set up during storm events. An evident problem is erosion of the upland area of the island due to overtopping of the existing protection. Backwash during return flow to the bay has also destroyed sections of the existing protection. The objective of the proposed revetment is to stabilize the island's perimeter and control overtopping related erosion to the upland and interior features.

Design criteria were set by NAB based on previous experience with projects in the Chesapeake Bay and the specific needs of the Bodkin Island project. A return period of 73 years was used for stability analysis, i.e. armor unit sizing. The 73-year return period was based on a 50 percent chance of design conditions occurring over the 50-year economic life of the project. Wave conditions and water levels associated with a 5-year return period were selected by NAB for determining upper limits of protection. Overtopping associated with extreme events may alter the upland and interior features, but these features can be reshaped after damage occurs. The revetment, however, should remain stable and require minimal maintenance.

Consideration was given to protection other than riprap revetment, including bulkheads and seawalls. However, riprap revetment was selected as the most feasible form of protection because of the relatively low cost of construction, the extensive experience and design guidance associated with riprap, and the low probability of failure. Other physical factors leading to the selection of riprap include: (a) resistance to wave energy, (b) simple and quick installation, (c) flexible planform, (d) easy maintenance and repair, (e) less structural damage due to uneven settlement, and (f) easy response to future island modifications.

The revetment design analysis required an assessment of the existing conditions at the site, an analysis of design wave conditions, and calculations for sizing and placing the riprap. The assessment of existing conditions included an accurate assessment of the bathymetry around the island, determination of design water levels, and collection of historic wind information for the wave analysis portion of the study. The wave analysis included determination of design wave heights, periods, and directions for waves attacking the island from several directions. The wave analysis also indicated the wave-attenuating effect of the large, flat shallows around the island. The revetment design calculations included determining the stable stone size, island side slopes, and the island crest elevation for the given design wave conditions, noting a minimal overtopping requirement. Each element of the riprap design analysis is described in detail below.

Existing Bathymetric and Geotechnical Conditions

Bathymetric data of the area surrounding Bodkin Island were collected by NAB and are shown in Figure 12. Additional digitized bathymetry covering a much larger area was obtained from the HL, WES, where the data were used for the study of currents in the Chesapeake Bay. Both data sets were combined and are shown in a contoured plot with surrounding land masses in Figure 13. Bathymetric data provided by NAB show depths ranging from -2.7 to -4.5 ft MLW near the island. Nearshore slopes surrounding the island are very flat with depths remaining in the -5 ft MLW range 700 ft away from the island. Such shallow depths may require dredging of a channel to permit barge access to the island during construction. Depths of 2.7 to 2.8 ft below MLW at a distance 500 to 600 ft northwest of the island favor orientation of the proposed island in that general direction. A very steep slope occurs 600 to 700 ft east of the island, with depth decreasing from 22 to 3 ft over a distance of only 100 ft.

NAB collected geotechnical data at specified locations of proposed construction surrounding Bodkin Island and along the channel in the Chester River to be dredged. Grain-size gradation curves indicate the dredged material from the Chester River to be used as fill consists of fine sands with an average D_{50} of 0.14 mm. NAB performed the drilling and testing programs, which consisted of six borings and performed analysis on the top 5 ft of the borings. The subsurface exploration performed by NAB indicated that the foundation condition around Bodkin Island generally consists of a 1- to 2-ft zone of soft silty sand, overlying a firmer fine sand.

Based on the above information and past experience with similar projects in the area, NAB recommended that approximately 1 ft of the soft silty sand can be expected to be displaced by the placement of any stone structure on the foundation, and that the quantity of stone required should reflect this displacement.

Bodkin Island presently contains both riprap and bulkhead structures along the perimeter. Bulkhead elevations are +4.0 and +5.0 ft MLW, and the crest elevation of the existing riprap was placed to +4.0 ft MLW as shown in Figure 14. The existing stone size seems adequate for stability; however, erosion and washout are occurring behind the structures due to overtopping. Interior island elevations range from +4 ft MLW adjacent to the bulkheads to a crest elevation of +9 to +10 ft MLW. Elevations above +5.5 ft are heavily vegetated and seem to be unaffected by related overtopping.

Wave Analysis

In order to adequately design the revetment for Bodkin Island, design wave heights, wave periods, and water levels were required. A wave analysis was conducted to determine the design wave heights and periods for the region. At the NAB's request, design wave conditions for a 73-year return period were determined and used for sizing the revetment armor stone, while wave conditions for a 5-year return period were determined and used for siting crest elevations (to minimize overtopping). Additionally, three wave propagation directions were considered for each return period. Waves from the east-southeast and southwest were considered the most significant because the long fetches permitted the largest wave growth. Waves from the north were determined and used for designing the sill structure on the north side of the island. The following are the wave analysis results, representing maximum wave heights and periods for each wind direction.

Direction (Azimuth)	N (0°)		ESE (112°)		SW (225°)	
Return Period, year	5	73	5	73	5	73
Wave Height, ft	1.6	2.6	1.8	3.2	3.0	4.2
Wave Period, sec	2.8	3.4	3.0	4.1	4.3	4.7
Storm Surge, ft	3.2	6.5	3.2	6.5	3.2	6.5

The design wave analysis was conducted using a two-dimensional spectral-energy wave model, called STWAVE, which is part of the CERC's Coastal Modeling System (draft report to be published later). The model has the capability to predict wave growth over a region for a given wind speed and direction accounting for bathymetric variations and fetch geometry. Standard fetch- and depth-limited calculations as given in the *Shore Protection Manual* (1984) were not used in this study because they do not account for varying bathymetry over the fetch, nor do they account for the effects of irregular fetches, wave refraction, and bottom diffraction.

A separate computational grid was used for each wave propagation direction, i.e. north, east-southeast, and southwest. Each grid boundary outline is shown in Figure 15 for reference. Note that a west-southwest grid is shown in Figure 15, but the results from that grid were not used in the design and are not presented in this report. Also, note that the southwest grid does not extend all the way down to the main stem of the Chesapeake Bay, and therefore does not represent the wave growth that would occur along the entire southwest fetch. To account for this problem, the wave height and period of waves entering the southwest boundary of the grid were estimated using CERC's Automated Coastal Engineering System (ACES) narrow fetch wave growth program (Leenknecht, Szuwalski, and Sherlock 1991). The STWAVE model then simulated the growth of the input wave conditions. The grid resolution was 184 ft between columns and 82 ft between rows.

Aside from providing the design wave characteristics identified above, the model study produced other worthwhile information. The model indicated that the historic "footprint" of the island (Figure 12) provided the island some level of protection from waves. All of the model results indicated that waves would grow continuously until they reached the edge of the footprint at which point further growth was retarded. The effect of Bodkin Island on sheltering Turkey Point from waves was inconclusive. The magnitude of the sheltering effect could not be ascertained from this wave study. It should be noted that STWAVE did not account for wave diffraction around the island. However, the wave heights taken from this study were used conservatively and therefore should duly compensate for diffraction effects.

The data required to conduct the wave analysis are provided in the subsequent paragraphs.

Design Winds

Design wind speeds and directions were required to calculate the design wave conditions. The design wind speeds and directions for each return period and wave propagation direction were provided by the NAB and are shown below.

Return Period, year	Wind Speed, knots		
	North	East-Southeast	Southwest
5	29.9	31.4	28.6
10	34.2	38.1	31.7
73	46.1	56.4	40.3

The 73-year event was not explicitly provided by the NAB but rather was interpolated between the 50- and 100-year return periods. The wind data were derived from the Patuxent Naval Air Station (PNAS) meteorological records which were assumed to be representative of the Bodkin Island region. The PNAS is located approximately 30 miles southwest of Bodkin Island. The winds were assumed to blow sufficiently long to generate fetch-limited waves, i.e., the waves were not duration limited. Also, the winds were not adjusted for overland-overwater differences. The adjustments would have lowered the wind speeds slightly or left them unchanged.

Design Water Levels

Design water levels for each return event were required for the wave analysis as well as the riprap design. The design water level data (astronomical and surge) for Bodkin Island were obtained from interpolation of Chen's (1978) water level data for Matapeake, Maryland, which is in the Chesapeake Bay proper at about the same northing as Bodkin Island. The water levels for Matapeake are probably higher than those for Bodkin Island because the island is located in the Eastern Bay which would dampen surge values. Therefore, the use of the Matapeake water levels was conservative. Also, the water levels for the given return periods were used regardless of the wind direction being considered. Yet, winds from the north and east tend to empty Eastern Bay, lowering the water level around Bodkin Island instead of inducing a water level setup. Thus, the water levels used with winds from the north and east were conservative. The tabulation below presents design water levels for each return period regardless of direction. Design water depths adjacent to the perimeter of the proposed island are also presented.

Design Event year	Design Water Level ft above MLW	Adjacent Depths Below Design SWL			
		N	ESE	SW	W
5	3.2	6.2	6.2	7.7	7.2
10	4.1	7.1	7.1	8.6	8.1
73	6.5	9.5	9.5	11.0	10.5

Design water levels used in the wave analysis and revetment design were obtained by adding the design water level (above MLW) from Chen to the regional bathymetry data (referenced to MLW) obtained from the NCS nautical chart No. 12270 (with modifications in the region around Bodkin Island based on the hydrographic survey completed by the NAB and dated 27 March 1991).

Containment Dike

A containment dike composed of rock spalls is to be constructed in order to properly retain the dredged material as it is placed. The dike will be constructed on a 1V:2H slope and placed to elevations of 6.5 and 5.5 ft above MLW for the southern and northern sections, respectively. Plan and cross-sectional views of the rock spall containment dike are shown in Figure 8. Rock spalls will be placed adjacent to the existing bulkhead on the southern section in order to achieve the same level of protection as the surrounding regions.

Revetment Design

The revetment design consisted of determining the armor unit size and crest elevation according to the available wave energy around the island. An attempt was made to optimize the revetment design along the perimeter of the island. Examination of the wave analysis results indicated the southern and northern sections would be exposed to different wave energies. Wave data used for design of armor unit weight and crest elevation of the southern and northern sections follow:

	Southern Section	Northern Section
Armor Size:	H_s = 4.2 ft	H_s = 3.3 ft
	T_p = 4.7 sec	T_p = 4.0 sec
Crest Elevation:	H_s = 2.7 ft	H_s = 1.9 ft
	T_p = 4.3 sec	T_p = 3.0 sec

Armor Unit Weight, Gradation, Thickness. The revetment was designed to remain stable during wave conditions corresponding to a 73-year event. The revetment was designed using ACES 1.06 Rubble Mound Revetment Design. Revetments for both the southern and northern sections were designed according to the design wave conditions for each section. The structural slope of 1V:2H was used for both sections since the containment dike would be constructed with the same uniform slope. Design output includes armor layer thickness and gradation. The input data, armor layer thickness, and armor layer gradation of both the southern and northern revetment designs follow:

Southern Section Rubble Mound Revetment Design		
Input		
Significant Wave Height	H_s	4.2 ft
Significant Wave Period	T_s	4.7 sec
Cotangent of Nearshore Slope	cot(phi)	100
Water Depth at Toe of Revetment	d_s	11.0 ft
Cotangent of Structure Slope	cot(theta)	2.0
Unit Weight of Rock	w_r	165 lb/ft^3
Permeability Coefficient	P	0.10
Damage Level	S	2.00
Armor Layer Thickness and Gradation		
Layer Thickness	r	3.37 ft
Percent Less Than by Weight	**Weight, lb**	**Dimension, ft**
0.0	99	0.84
15.0	315	1.24
50.0	788	1.68
85.0	1545	2.11
100.0	3153	2.67

Northern Section Rubble Mound Revetment Design		
Input		
Significant Wave Height	H_s	3.28 ft
Significant Wave Period	T_s	4.0 sec
Cotangent of Nearshore Slope	cot(phi)	100
Water Depth at Toe of Revetment	d_s	9.5 ft
Cotangent of Structure Slope	cot(theta)	2.0
Unit Weight of Rock	w_r	165 lb/ft^3
Permeability Coefficient	P	0.10
Damage Level	S	2.00
		(Continued)

Northern Section Rubble Mound Revetment Design (Concluded)		
Armor Layer Thickness and Gradation		
Layer Thickness	r	2.58 ft
Percent Less Than by Weight	**Weight, lb**	**Dimension, ft**
0.0	44	0.65
15.0	142	0.95
50.0	355	1.29
85.0	695	1.62
100.0	1420	2.05

Crest Elevation. The crest elevation of the revetment was designed to minimize overtopping for wave conditions corresponding to a 5-year event. Tolerable overtopping rates for an unprotected backslope (i.e., clay, compacted soil, grassed) are 0.05 cfs/ft (Hydraulics Research Station 1990). Irregular wave runup and overtopping rates were computed using ACES 1.06 Irregular Wave - Rough Slope Runup and Overtopping. Overtopping rates were calculated for both the southern and northern sections to determine the appropriate crest elevations. A design water level of 3.2 ft above MLW was applied for the 5-year event. Average water depth was 4.5 ft for the southern section and 4.0 ft for the northern section. Rough slope coefficients for a riprap structure were applied for runup calculations. Overtopping coefficients were a function of structure slope, water depth at the structure, and wave height and period. Overtopping rates were calculated for a range of crest elevations for each section and are represented below.

Top of Armor Elevation ft above MLW	Overtopping Rates, cfs/ft	
	Southern	**Northern**
4.0	—	0.648
4.5	—	0.212
5.0	0.433	0.062
5.5	0.205	0.017
6.0	0.092	0.004
6.5	0.039	0.001
7.0	0.017	0.000
7.5	0.006	—
8.0	0.002	—

Splash Apron. The overtopping calculations determined that the armor layer can terminate at elevations of 6.5 and 5.5 ft above MLW for southern and northern sections, respectively. Upland areas are to be constructed to an initial elevation of +10 ft MLW. In order to protect the fill during significant events, a splash apron should be placed along the exterior slope and continue across the crest for a distance of 5 ft. The splash apron could be composed of the rock spalls placed two layers thick depending on the average weight of the spalls. An effort should be made to place the larger stones in the rock spall gradation along the slope of the apron. Runup and overtopping during extreme events may alter the splash apron and require reshaping. Modifications to the apron's stone size may be necessary if extensive damage is frequently observed during monitoring.

Toe Protection. Based on design guidance in EM 1110-2-1614 (Headquarters, Department of the Army 1985), the cover for the toe apron of a revetment should be an extension of the lowest cover layer on the revetment slope. The toe apron should be buried wherever possible, with the revetment cover layer extended into the bottom for at least the distance of the maximum unbroken wave height expected in low water conditions. Given an average low water depth of 3 ft, the maximum breaking wave height available is approximately 2.5 ft. Therefore, the cover layer should extend to 2.5 ft beneath the surface. The buried toe should extend horizontally an additional distance equal to twice the toe's depth, or 5.0 ft. The geotextile may be extended beyond the edge of the apron, folded back over the bedding layer and some of the cover stone, and then buried in cover stone and sand to form a Dutch toe.

Geotextile Selection. The geotextile prevents migration of the fine particles through the voids in the structure, distributes the weight of the stone to provide more uniform soil settlement, and permits relief of hydrostatic pressures within the soil. The geotextile is to be placed beneath the rock spalls during construction of the containment dike and along the interior of the dike before placement of the dredged fill. Depending on the expected rock spall gradation, geotextile may be required between the rock spalls and armor layer to prevent the rock spalls from being washed through the voids. The geotextile should satisfy filter, strength, and other survivability requirements expected for the project. Gradation of the rock spalls, dredged fill material, and underlying foundation must be determined before specification of the required geotextile can be made.

Revetment Design Summary. Cross sections of both the southern and northern structures are shown in Figures 16 and 17. The containment dike, riprap armor layer, toe protection, splash apron, and geotextile are shown with proper elevations, thickness, and locations. Figure 18 shows the riprap layout in plan view, indicating limits of the southern and northern sections and locations of existing riprap and bulkhead sections. Modifications to the existing riprap are also shown on Figure 18.

Sill Design

The sill structure located on the northern side of the proposed island will allow periodic inundation of the island's interior. A channel (tidal outlet) is located in the sill to allow regular tidal flow through the tidal creeks.

The entire sill structure was designed to remain stable during a possible 73-year event occurring directly from the north, the only direction from which waves are able to impact the sill. A significant wave height of 2.6 ft and a peak wave period of 3.4 sec were used for stability analysis. The entrance to the sill consists of a 1V:6H slope from the bay bottom (-3 ft MLW) to the crest of the sill (+1 ft MLW). Using the Hudson Formula (*Shore Protection Manual* 1984) with a stability coefficient of 2.5, produced a median stone size, W_{50}, of 100 lb. The minimum thickness required (n = 2 stones thick) is 1.7 ft.

The crest height and width of the sill required to dissipate expected wave heights were estimated using a wave transformation routine in NMLONG (Kraus and Larsen 1991), a CERC littoral transport program which can calculate wave transformation across defined boundaries. The crest elevation required is a function of expected water level since the waves allowed to pass over the sill will be depth-limited. As stated in the wave analysis section, winds from the north are not expected to significantly elevate water levels. An elevation of 1 ft above MLW was selected as the design crest elevation. This elevation matches the elevation of the fill behind the sill. Under normal conditions, waves are expected to shoal on the 1V:6H slope and break on the sill. The addition of vegetation directly behind the sill will further dissipate the wave energy. A sill width of 35 ft was chosen to join the adjacent revetment structure. This width is conservative compared to the estimate from NMLONG. Cross sections of the sill are shown in Figure 19.

Material Volumes/Requirements

A summary of estimated stone and geotextile quantities required for the proposed structures is found in Table 1. The summary presents the quantity of material required for each individual section. The sections are defined by description and azimuth range and list the approximate perimeter length. Total estimated armor stone, rock spall, and geotextile requirements are presented to easily obtain a rough cost estimate. Appropriate adjustment factors should be applied to the quantities to account for construction losses during placement, including overlap requirements and slack layout of the geotextile.

Table 2 lists the approximate volume and tonnage of armor stone required for southern and northern sections, transitions, existing riprap sections, and the sill structure with lengths obtained from Figure 18. Table 3 lists the approximate volume and tonnage required for the rock spall containment dike. Lengths corresponding to each section were obtained from Figure 8. The approximate amount of geotextile required is broken down for various sections as shown in Table 4. Cross sections demonstrate how the geotextile is to be placed for the sections.

7 Numerical Model Study of Impacts of Island Enlargement on the Surrounding Bay

A numerical model study was conducted to determine if the enlarged island will cause significant changes to the flow field around Bodkin Island. The predictions of velocities and tide levels in the vicinity of Bodkin Island were accomplished with a mathematical model. A hydrodynamic model generated the time-varying currents and water elevations at computational nodes in a numerical mesh representing the Eastern Bay of Chesapeake Bay. The numerical model, RMA-2V (A Two-Dimensional Model for Free-Surface Flow), is included in the TABS modeling system, which is supported by the USACE (Thomas and McAnally 1985).

Numerical Model

Model Limits. A numerical mesh of Eastern Bay was developed using bathymetry obtained from NOS nautical chart No. 12270 and, in the vicinity of Bodkin Island, recent bathymetric survey data (Figure 20). A state coordinate (x-coordinate and y-coordinate) and a z-value (bed elevation) were assigned to each node in the mesh through the use of a digitizer. The vertical datum was set to MLW. The mesh is made up of 5,211 nodes, comprising 1926 elements.

Time-step. The time-step used in the hydrodynamic numerical simulations was 30 min (0.5 hr).

Boundary Conditions. If no boundary condition is specified at a node, RMA-2V computes an x- and y- component of velocity and a water depth. For boundaries along land/water interfaces, slip flow parallel to the boundary is specified. Along a line from Kent Point to approximately 1 mile south of Wades Point, a time-dependent water-surface elevation was assigned to the boundary nodes to represent tidal elevation fluctuations. (No tidal elevations were specified at the Kent Island Narrows.) For the initial investigations, the tidal fluctuations at Kent Point were defined as a simple sinusoidal function with a range of 1.1 ft and a period of 12.5 hr.

The roughness coefficients for each element in the mesh were assigned according to the element's average depth and size. Figure 21 shows the regions covered by the elements of types 1, 2, and 3. Types 4 and 5 were the very small elements in the vicinity of Bodkin Island. Type 5 was used in the plan test to represent the marsh elements. The types correspond to the following roughness and depth regions:

Type	Manning's N (roughness)	Depth (ft MLW)
1	0.023	6 - 30
2	0.025	0 - 6 (except in the vicinity of Bodkin Island)
3	0.020	≥ 30
4	0.030	0 - 6 (vicinity of Bodkin Island)
5	0.035	0 - 6 (marshy areas within Bodkin Island, Plan)

Enlargement Plan. Figure 22 shows the suggested improvements to Bodkin Island. Important features are the breakwater to the north, the raised dike surrounding tidal ponds and marsh, and a submerged sill at the entrance channel to the enlarged island's interior. The breakwater shown in Figure 22 was removed from the design after the numerical study was complete. Figure 23 shows an enlargement of the mesh in the area of Bodkin Island. In order to simulate the test plan, the elements comprising the dike and breakwater were changed to type 0 (therefore, eliminating them from the computations), and the bed elevations were changed to the appropriate values for the interior ponds, channels, and marshes.

Numerical Model Results. Figure 24 shows the locations of selected nodes. Figures 25 to 31 show comparisons of water velocity between the base and plan conditions. Figures 32 and 33 show water-surface elevation comparisons between nodes 2038 and 3672. All the velocity values are relatively low (≤ 0.5 ft/sec). The most significant changes in the velocities occur in the area to the northwest of Bodkin Island. Nodes 2904 and 3177 are to the upper left and upper right of the proposed breakwater. Node 3672 is in the area behind the proposed breakwater, along the axis of the entrance channel. These areas would be expected to have the most difference. The water-surface elevation is not changed by the plan.

Figures 34 and 35 show vector plots of velocity at maximum ebb and flood, respectively, for the base conditions. Figures 36 and 37 show the same for the plan conditions. Figures 38 and 39 show the "difference" (i.e., plan - base) vectors between plan and base conditions. The absence of significant vectors indicates no change between base and plan. It is evident that the effects of the plan would be very limited and localized. The absence of the breakwater in the final design does not change these conclusions.

Data Collection Program

Field data were collected by WES personnel during June 1991. Tide elevation data were collected 7-9 June 1991 at Kent Point and at a point approximately 500 ft south of the Kent Island Narrows. Tide data were collected using Environmental Devices Corporation (ENDECO) model 1029 water level recorders. The ENDECO model 1029 recorders contain a strain gage type pressure transducer located in a subsurface case which is used to record the absolute pressure of the column of water above the case. The pressure is measured for 49 sec of each minute of the recording interval with a frequency of 5-55 kHz to filter out surface waves. The accuracy is ±0.1 percent of full scale (0-50 ft). The sampling time interval was set to 5 min. The time histories of the water levels (corrected to MLW) are shown in Figure 40.

Water velocity data were collected in the vicinity of Bodkin Island on 8 June 1991. Stations were selected based on the results of the previously discussed numerical modeling (which show a northeast-southwest, flood/ebb pattern) and the proposed plan. Station 1 is to the north of the island, just beyond the location of the proposed breakwater. Stations 2 and 3 (on a line running northeast from the island) and stations 5 and 6 (on a line running southwest from the island) were chosen to enable a measurement of the strength of eddies created by the flood/ebb cycle. Station 4 is just southeast of the island. Figure 41 shows the locations of each station. The weather on 8 June 1991 was cooler than normal with very little cloud cover. The wind was generally from the southwest and less than 5 mph.

The InterOceans Model S-4 electromagnetic current meter was used to measure both current speed and direction (velocity). The S-4 meter is a 10-in.-diam sphere that measures the current using an electromagnetic field to sense current induced by the movement of water through the field. The accuracy of the S-4 current meter is 2 percent of the reading or about ±0.03 ft/sec. All velocity measurements were taken at a depth of 2 ft above the bottom and represent 20-sec averages. Readings were done on an hourly basis, with three successive readings at each station (to determine the amount of variability to expect). Figures 42 to 53 show vector plots of the measured velocities. The collected data were also tabulated in Table 5.

Model Validation

Rigorous verification of the numerical model was beyond the scope of this study. However, one model simulation with the water levels collected at Kent Point from 7-9 June 1991 was done (no water level boundary conditions were defined at the Kent Island Narrows, as in the initial simulations). No attempt at refinement of the model's mesh or other hydraulic parameters was made. The results of this simulation are plotted versus field data in Figures 54 to 56. Although the model results are not identical to the field measurements, the results are encouraging given the amount of variability in the field data. In general, velocity magnitudes agree in range to those found in the field.

8 Vegetation

One of the important but relatively smaller costs of this wetland habitat project will be plant materials, labor, and transportation in planting the island. Planting is recommended in lieu of natural colonization to ensure rapid vegetation cover on the new island to lessen potential impacts on nesting areas and to hasten development of brood habitat. Planting will also help keep out undesirable plant species such as common reed (*Phragmites australis*).

There are four options that could be used in combination with complete planting, or in lieu of planting, to reduce costs of plant material and labor. These four are: (a) sowing a mixture of seeds of appropriate species rather than sprigging; (b) allowing some portions of the island to colonize naturally; (c) widen plant spacings (e.g., rather than 3-ft centers, use 4- or 5-ft centers); and (d) use plants from donor stands rather than nursery-grown plant material. Sprigs collected and planted by volunteers such as Boy Scouts, Girl Scouts, 4-H Clubs, school classes, or adult conservation groups could also reduce costs. If a contract is used for island planting, these details can be worked out with mutual consent of all interested parties.

Whether sprigs or seeds are used, since the dredged material will be almost pure sand and therefore will rapidly leach out immediately available nutrients, all plantings should be accompanied by use of a slow-release fertilizer to provide a boost to initial growth and survival. Once plantings are established, continued fertilization will not be necessary. Care must be taken not to overfertilize the plantings, so that excess nutrient buildup cannot occur in the two tidal pools and cause an algal bloom or other undesirable effects.

Initially, plantings will probably require protection from predation by waterfowl. In the Chesapeake Bay area, geese are especially bad about flocking to new, fertilized plantings and eating both top shoots and roots/rhizomes. Waterfowl predation of young plants is difficult to prevent, but can be controlled by use of hog wire laid over a site, with sprigs planted between the wires, or use of diversions and scare tactics such as scarecrows, propane cannons, and flagging.

Upland Nesting Areas

The upland nesting areas include the crest of the island immediately behind the riprap face, and the upper interior slope down to approximately +4.0 ft, a width of approximately 61 linear ft, and an approximate 53,000 sq ft of new nesting habitat. Black duck nesting requirements are relatively low, dense cover such as vines and shrubs, mixed with some grass species. On the existing island, the largest concentration of black duck nests were on the shrubby, viney crest, near the standing pine snag.

Four plant species are recommended for planting on the crest and upper slopes. These include, Japanese honeysuckle (*Lonicera japonica*), poison ivy (*Rhus radicans*), saltmeadow cordgrass (*Spartina patens*), and black cherry (*Prunus serotina*). The shrub planting design calls for planting clusters of five plants (potted, well-rooted, 1-gal containers) on 6-ft centers at 100-ft intervals on the crest of the island. Black cherry can be obtained commercially. Plant material requirements are given in Table 6.

Japanese honeysuckle and poison ivy are vine species, although poison ivy also has a shrub form that could be used as an alternative. Hens prefer building nests under low-growing viney cover, and while poison ivy is not a deterrent to ducks, it could help keep human intruders away from the nest sites. Neither species is available commercially; however, rooted nodes of Japanese honeysuckle can be obtained from old fields and natural areas, and seeds of poison ivy can be gathered and propagated if necessary or seeds sown as an alternative to planting rooted sprigs. Should it be impossible to obtain poison ivy plants or seeds, alternative hardy vine species or low-growing legumes or forbs could be substituted.

Saltmeadow cordgrass is a grass highly adapted to the coastal zone in a variety of wet conditions. It will grow from the mean low high tide (MLHT) zone up to the crests of dunes in Chesapeake Bay. It is recommended for planting in two habitats on the island. The first use is as a nurse-crop on the crest and upper slopes to help hold sand until the other plant species can establish. The planting design in the upper habitat calls for every fourth plant on 3-ft centers to be saltmeadow cordgrass, with three each of Japanese honeysuckle or three each of poison ivy between the cordgrass sprigs (3 JH: 1 SC: 3 PI: 1 SC: 3 JH:, etc.).

High Marsh Zones

The high marsh zone occurs on the 1V:6H interior midslope between +1.0 and +4.0 ft. Salinities around Bodkin Island are usually not higher than 12 parts per thousand, and a number of high marsh species could potentially do well in this zone. In keeping with the nesting and brood requirements of black ducks, five plant species are recommended for planting. These species include marsh elder (*Iva frutescens*), saltgrass

(*Distichlis spicata*), saltmarsh bulrush (*Scirpus robustus*), Olney's threesquare (*Scirpus olneyi*), and saltmeadow cordgrass. Plant material requirements are given in Table 6.

Marsh elder is a relatively common, often weedy shrubby plant of brackish marshes. In the Bodkin Island area, it should grow best between +2.0 and +4.0 ft. Plantings should be planted on 3-ft centers and clustered at that elevation among the other species.

Saltgrass is also adapted to a wider elevational zonation and can grow at +1.0 to +4.0 ft. Sprigs should be planted on 3-ft centers in mixed stands with saltmeadow cordgrass. Saltmeadow cordgrass can grow well throughout the entire high marsh zone and should be planted on 3-ft centers in mixed stands with saltgrass up to +4.0 ft, with sea oxeye in its stricter zonation and with saltmarsh bulrush and Olney's threesquare at the lowest part of this zone (+1.5 to +2.0 ft).

Both bulrush species are hardy competitors in the lowest part of the high marsh zone and also provide excellent food items for a variety of wild-life, including waterfowl, songbirds, and small mammals. The introduction of these two species to Bodkin Island will add to the diversity of habitat and the quality of brood habitat for ducklings. Both species should be planted in mixed stands on 3-ft centers, mixed with saltmeadow cordgrass, but only to the +3.0-ft elevation.

Low Marsh Zones

Smooth cordgrass (*Spartina alterniflora*) is the only plant species that grows well at -1.0 to +1.0 ft in brackish and salt marshes in Chesapeake Bay. It should be planted at those elevations on 3-ft centers throughout the entire island, around the tidal pools, and along the banks of the tidal outlet and small channels. There is no need for additional stabilization due to the protection that the island interior affords. At +1.0 to +1.5 ft, saltmeadow cordgrass and other mid to high zone species will colonize and grow interspersed with the smooth cordgrass plantings.

Tidal Pools

Once vegetation is well established on the rest of the island, aquatic plants can be introduced to the tidal pools. While the island is under construction, and immediately thereafter, it is entirely likely that there may be higher temporary turbidity levels as soils are settling and until plant cover is denser. The recommended species, horned pondweed (*Zennichellia palustris*), redhead grass (*Potamogeton perfoliatus*), sago pondweed (*Potamogeton pectinatus*), and widgeongrass (*Ruppia maritima*), will not grow well under poor water quality conditions. Therefore, these plants should NOT be introduced to the tidal pools until about one year after initial planting of the wetland areas. Aquatic plant species can be introduced to the tidal pools using stock from other locations in the bay. The tidal outlet and small channels will not require planting; aquatic vegetation may naturally colonize in these areas. Smooth cordgrass will grow down to -1.0 MLW and will occupy part of the pools. However, at least an 80-ft-diam open water should occur in each pool.

Special Features

There are several prominent features associated with Bodkin Island. One special feature is the four osprey nesting platforms to encourage ospreys to live on Bodkin Island. These platforms should be located on opposite sides of the island on the crest at least 10 ft behind the riprapped face. Platform designs are available upon request from WES and are part of the USACE Wildlife Management Techniques Manual Series. Heights of the four platforms should vary. The pine snag should be allowed to remain as long as it will stand to ensure transition from the snag to the platforms.

Another special feature is the tidal outlet and small streams connecting the tidal pools to the bay and to each other and providing more efficient tidal dispersion throughout the wetland. These tidal creeks should be excavated not deeper than -1.0 ft MLW, so that they cannot completely drain the tidal pools. The tidal outlet will flow through another special feature, the rock outlet on the north end of the island (Figure 9). Riprap must be placed at the entrance of the tidal outlet at -1.0 MLW to ensure that the outlet will not wash deeper than that elevation, thereby draining the tidal pools.

The most prominent special feature is the riprap face of the island. At a 1V:2H slope, the riprap will provide not only storm and wave protection but also a hard, rough substrate under shallow water and in the intertidal zone for use by shellfish, other invertebrates, and small fishes. No introduction of species is necessary; when the riprap is placed, natural colonization will occur.

9 Summary and Recommendations

Bodkin Island restoration will be accomplished by reestablishment of brood habitat and improvement and additions to nesting habitat. The restoration will use 45,000 cu yd of dredged material that will be placed on the north side of the existing island and then shaped and stabilized to prevent erosion. Future additions of dredged material to Bodkin Island could be easily connected to the initial enlargement on the northern open end of the island.

Construction of the island will require a containment structure to minimize the loss of dredged material during placement. Small riprap or quarry spall is recommended for the containment structures.

The habitat restoration includes an upland/high marsh/low marsh gradation from the island crest down to tidal pools that will provide shallow water for use by black duck hens and broods of ducklings. The restoration plan includes installation of four osprey nests.

Stability of the island interior will be ensured by sizing the tidal creeks large enough to prevent erosion and by providing a rock-lined tidal inlet channel. Deposition in the tidal creeks is expected until a stable or equilibrium cross section is achieved.

Storm surge and wind wave analysis and revetment design provide a plan for long-term stability of the enlarged island. Design wave conditions used to determine riprap stability and elevation were determined through the use of a two-dimensional spectral-energy wave model called STWAVE. The revetment height is based on preventing significant damage from overtopping which is causing damage to the existing island.

The island's tidal opening on the north side will be protected by armor stone having W_{50} of 100 lb.

Numerical modelling of the Eastern Bay shows that the island enlargement will have negligible effects on the tidal current patterns except for areas immediately adjacent to the island.

A vegetation plan is developed that provides habitat and island stability. Planting is recommended in lieu of natural colonization. The vegetation plan provides different planting schemes for upland nesting, high marsh, low marsh, and tidal pools and creeks.

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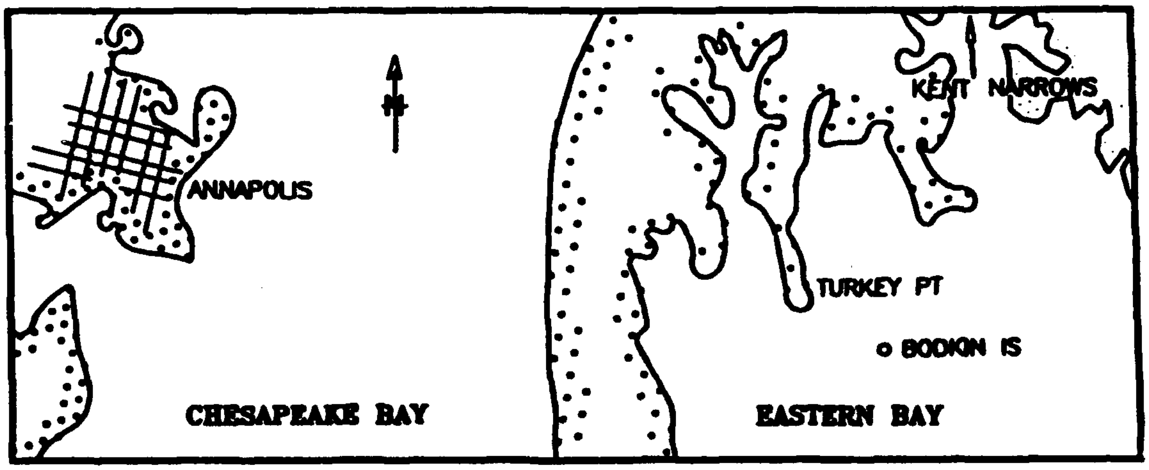


Figure 1. Location map

Figure 2. A view of Bodkin Island in January 1991, showing the bulkhead shoreline from the north, the standing vegetation, and the tall dead pine snag and osprey nest

Figure 3. The bulkheaded shoreline has failed in several places, and riprap was placed by the private landowner to slow erosion of the island

Figure 4. A view of the Bodkin Island crest, showing the best remaining black duck nesting area, located on the eastern side of the island

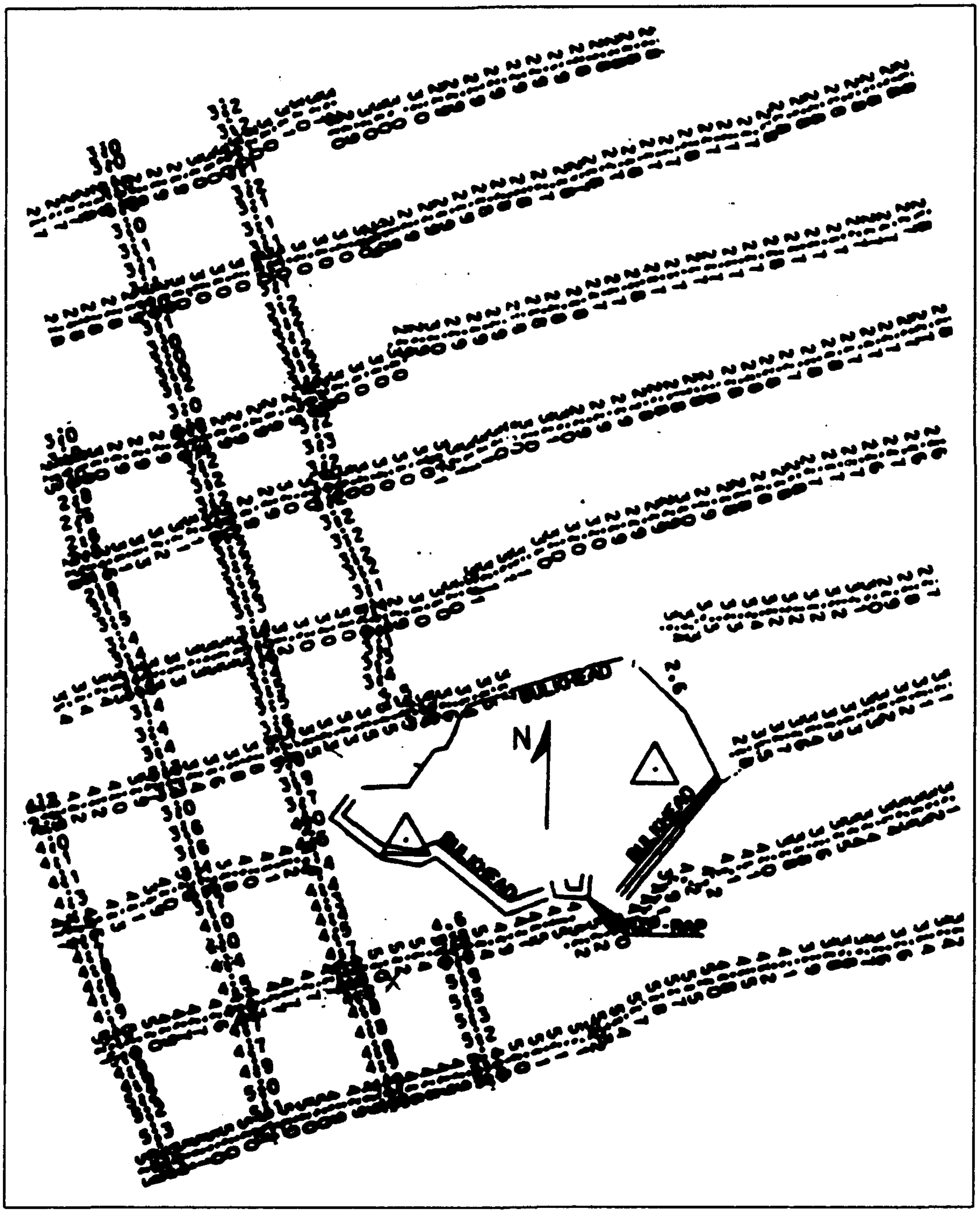


Figure 5. Bathymetric data (depth below mean low water)

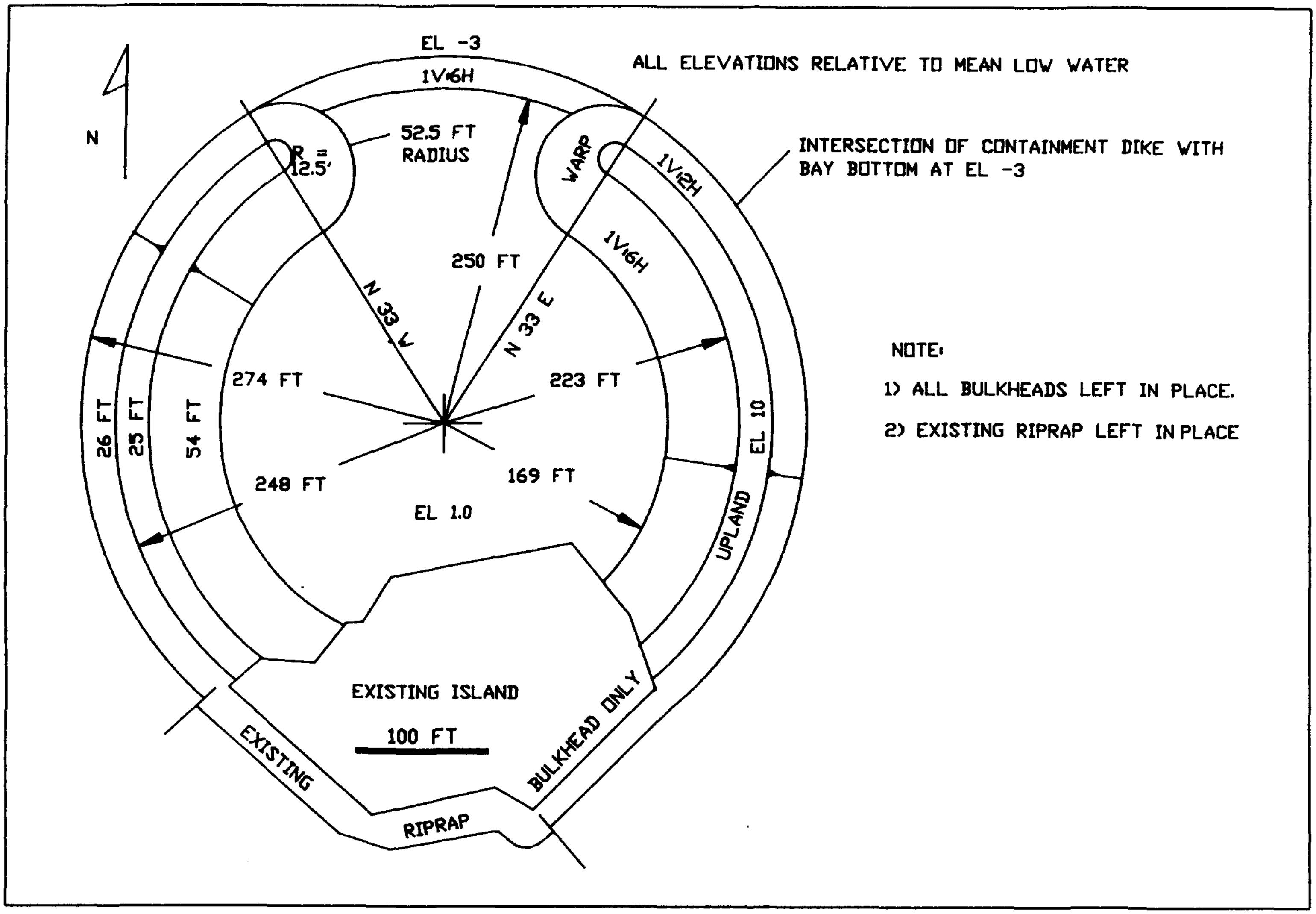
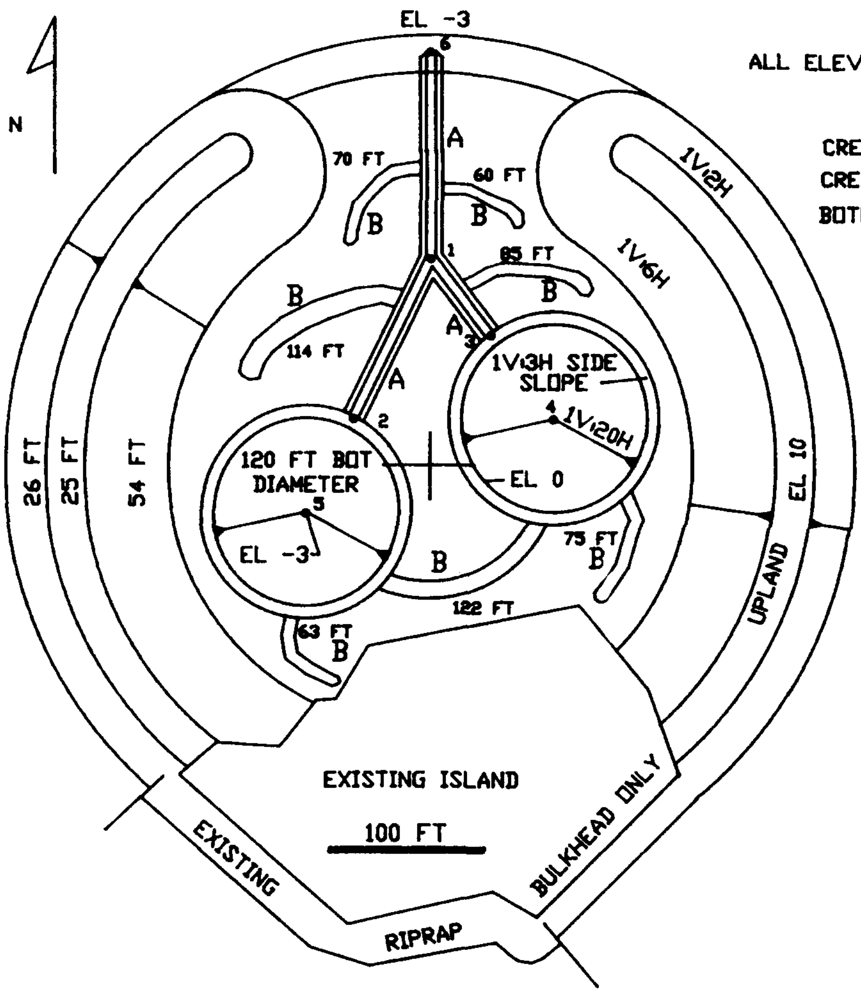


Figure 6. Island plan



ALL ELEVATIONS RELATIVE TO MEAN LOW WATER

CREEK TYPE A HAS 6 FT BOTTOM, 18 FT TOP
CREEK TYPE B HAS 3 FT BOTTOM, 15 FT TOP
BOTH HAVE 1V:3H SIDE SLOPES, BOTTOM EL -1

POINT	POSITION RELATIVE TO CENTER OF ISLAND
1	130 FT NORTH
2	29 FT NORTH, 50 FT WEST
3	82 FT NORTH, 38 FT EAST
4	30 FT NORTH, 80 FT EAST
5	30 FT SOUTH, 80 FT WEST
6	263 FT NORTH

LENGTH OF CREEK TYPE B SHOWN.
POSITION AND ALIGNMENT SHOULD
BE SCALED FROM DRAWING.

Figure 7. Island plan with tidal ponds and creeks

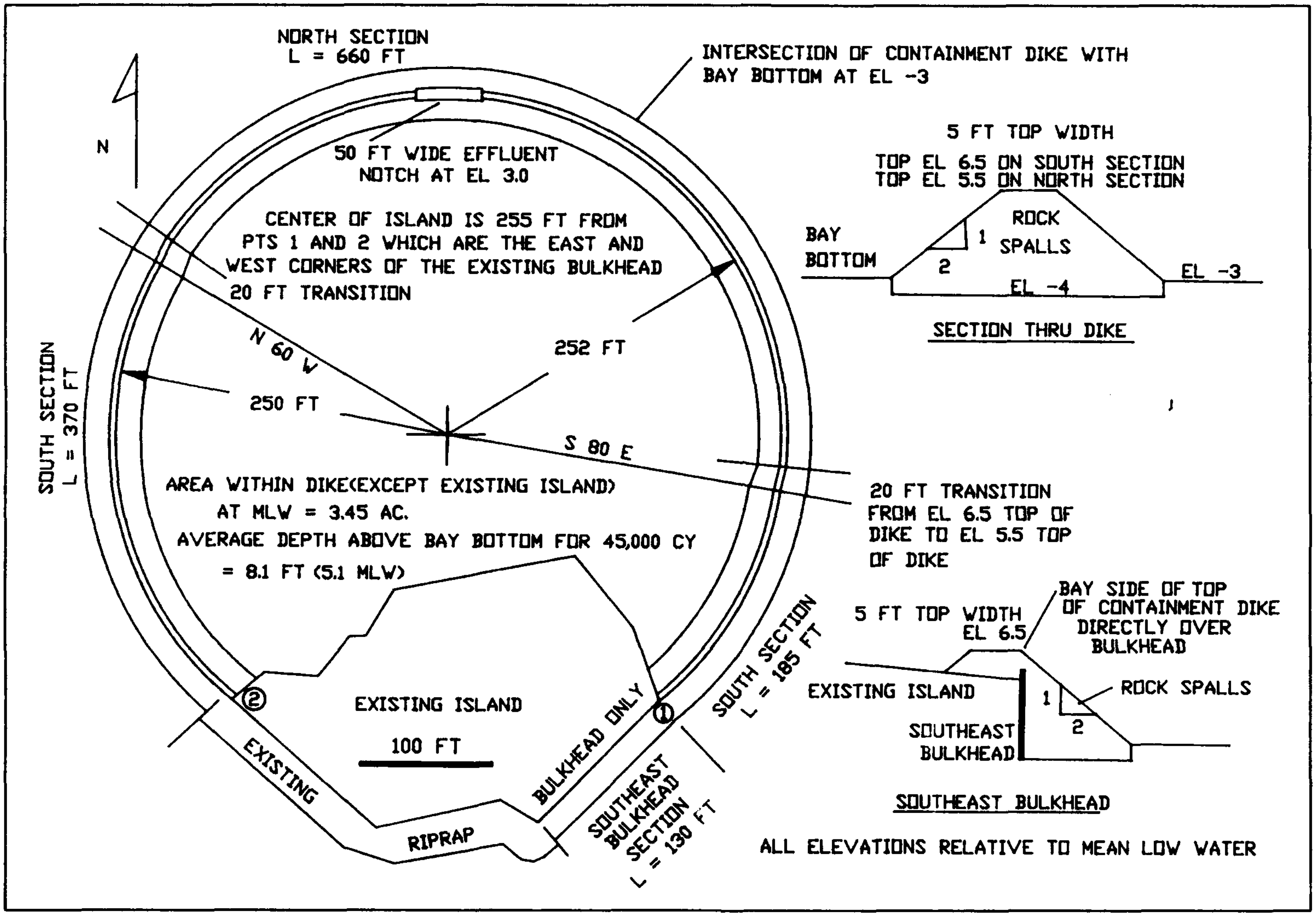


Figure 8. Rock spall containment dike

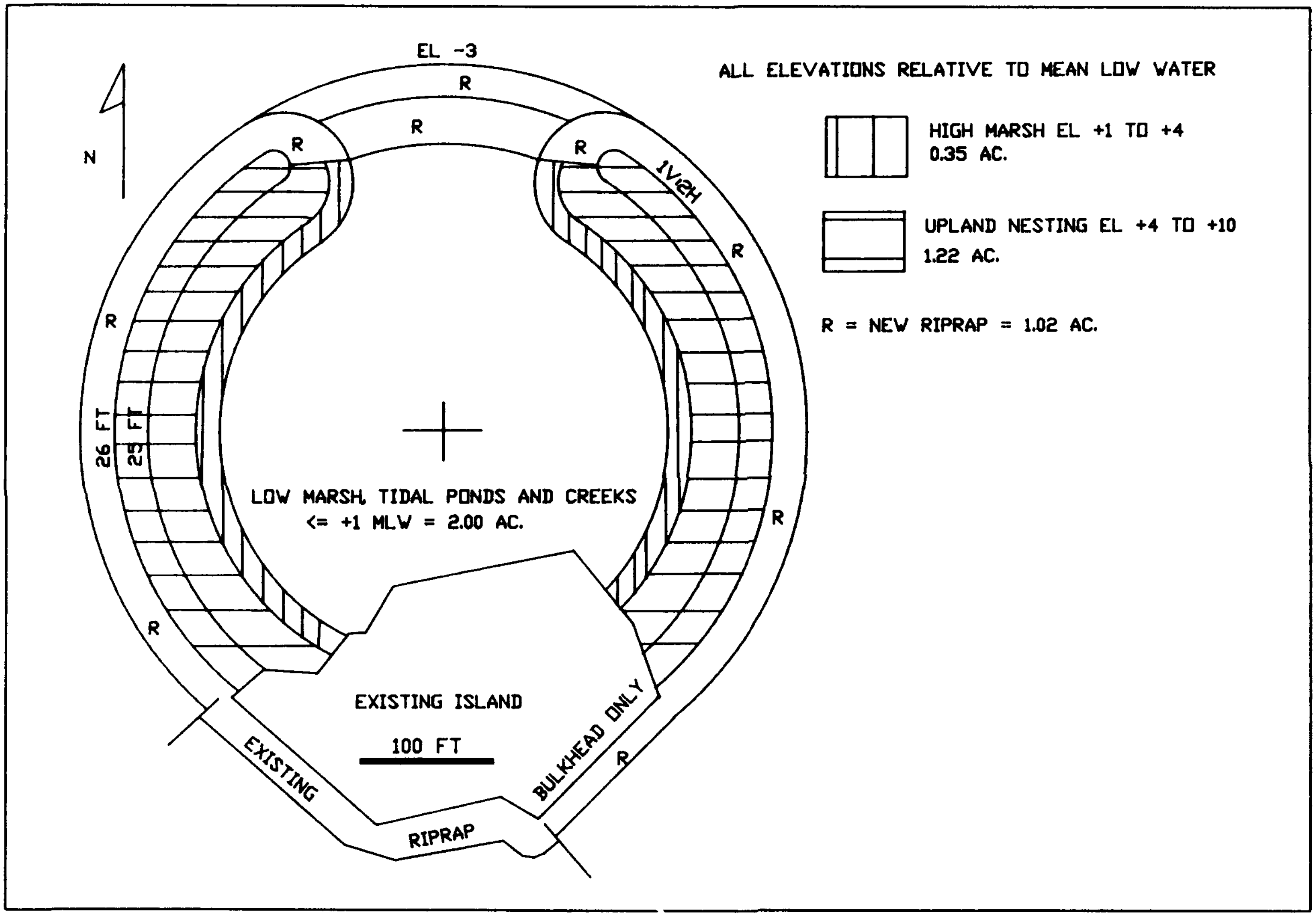


Figure 9. Habitat areas

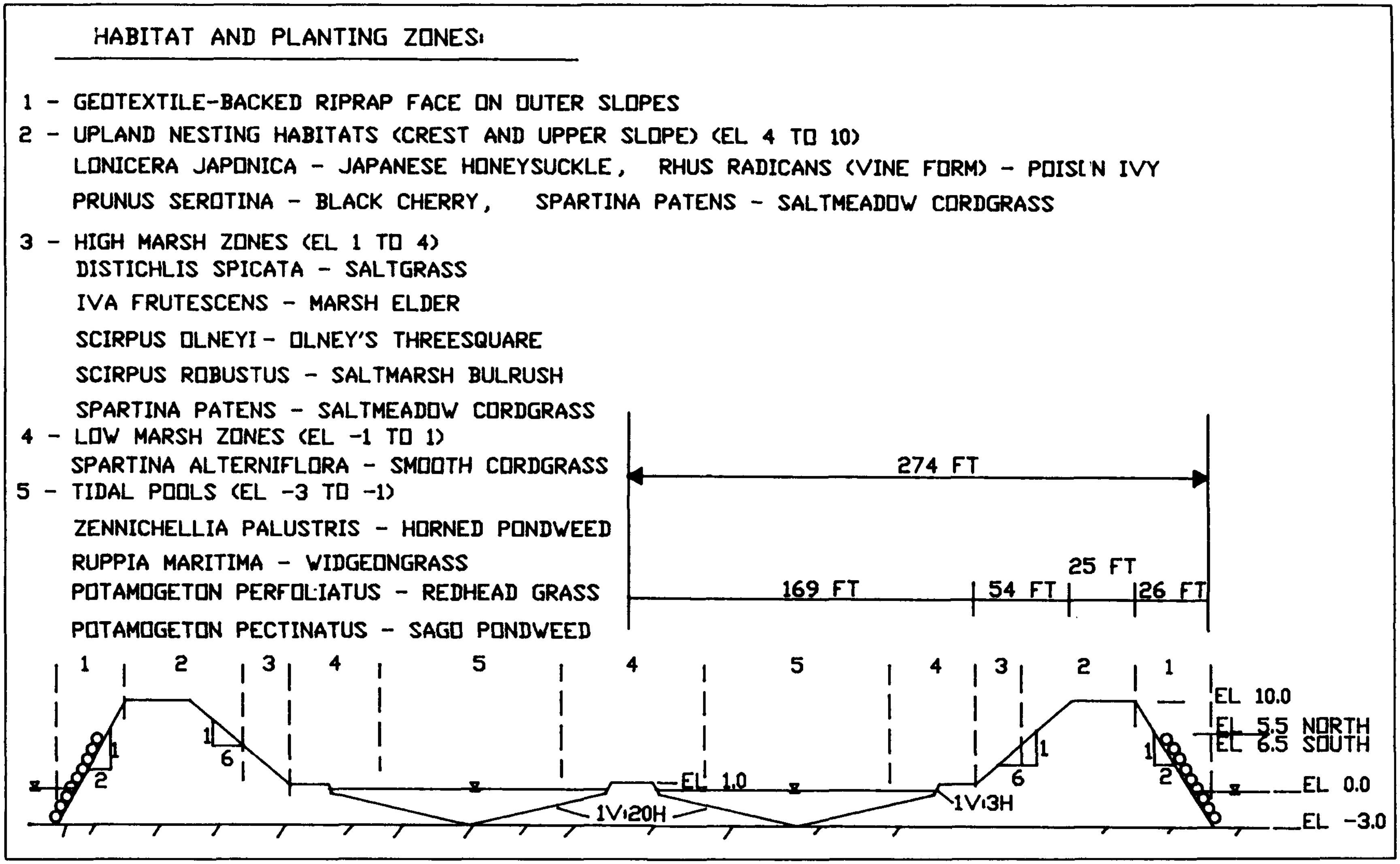


Figure 10. Cross section of habitat and planting zones

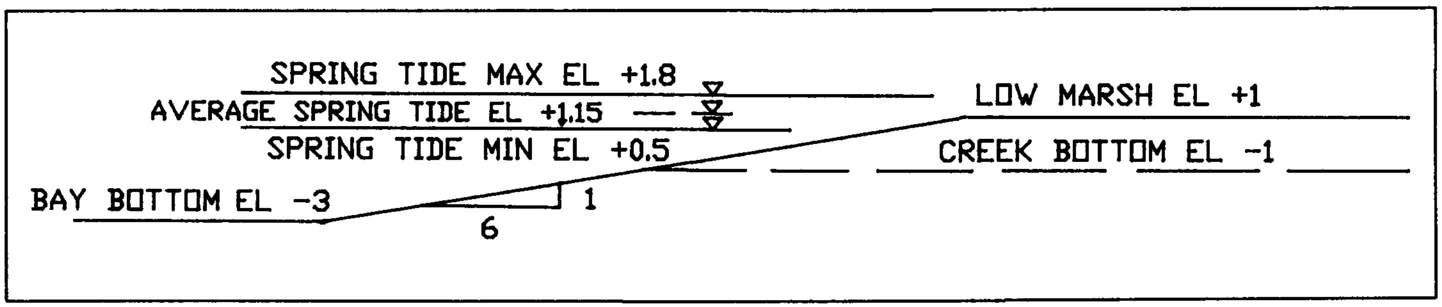


Figure 11. Schematic of spring tide used in channel stability analysis

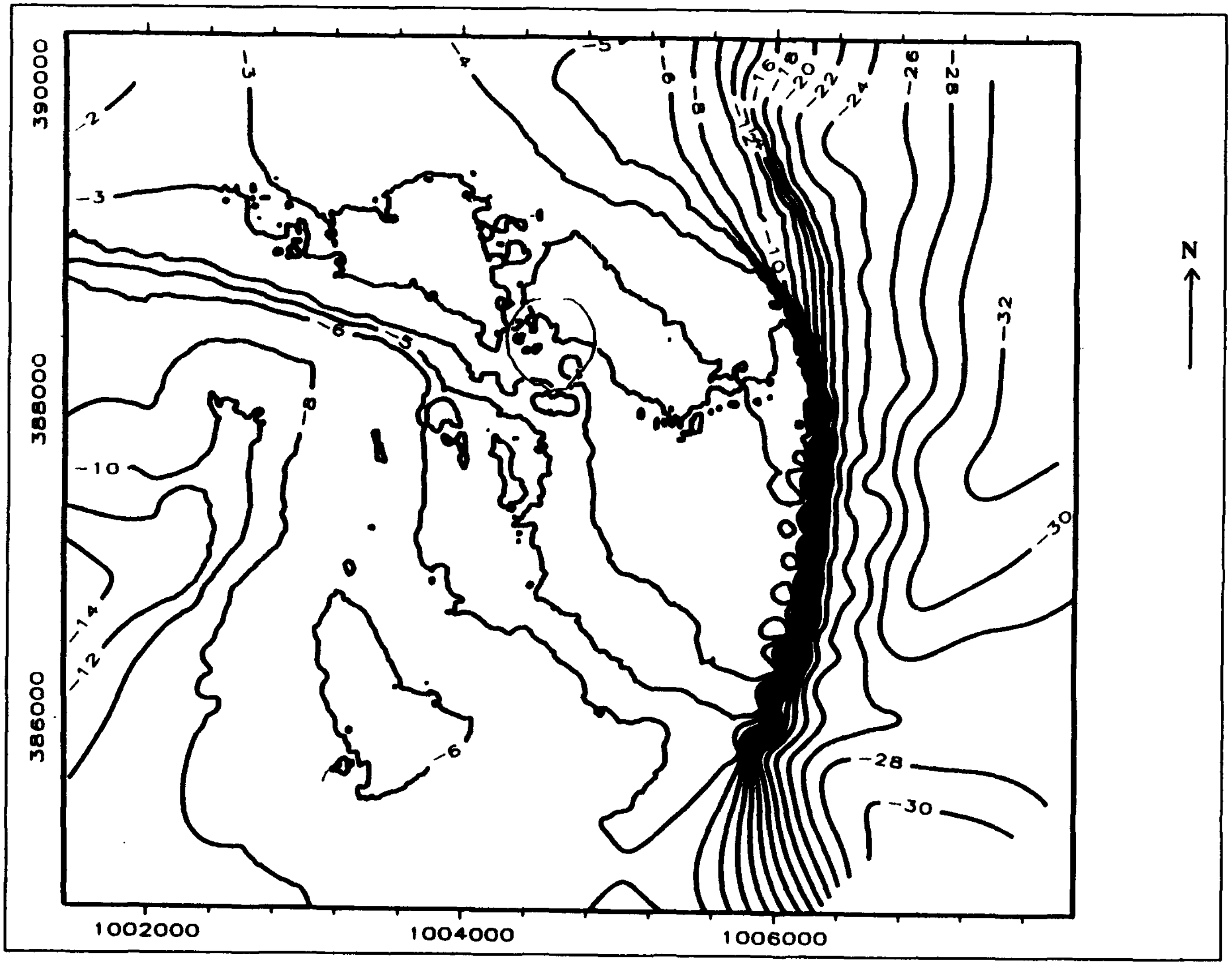


Figure 12. Contour map of local bathymetry provided by NAB

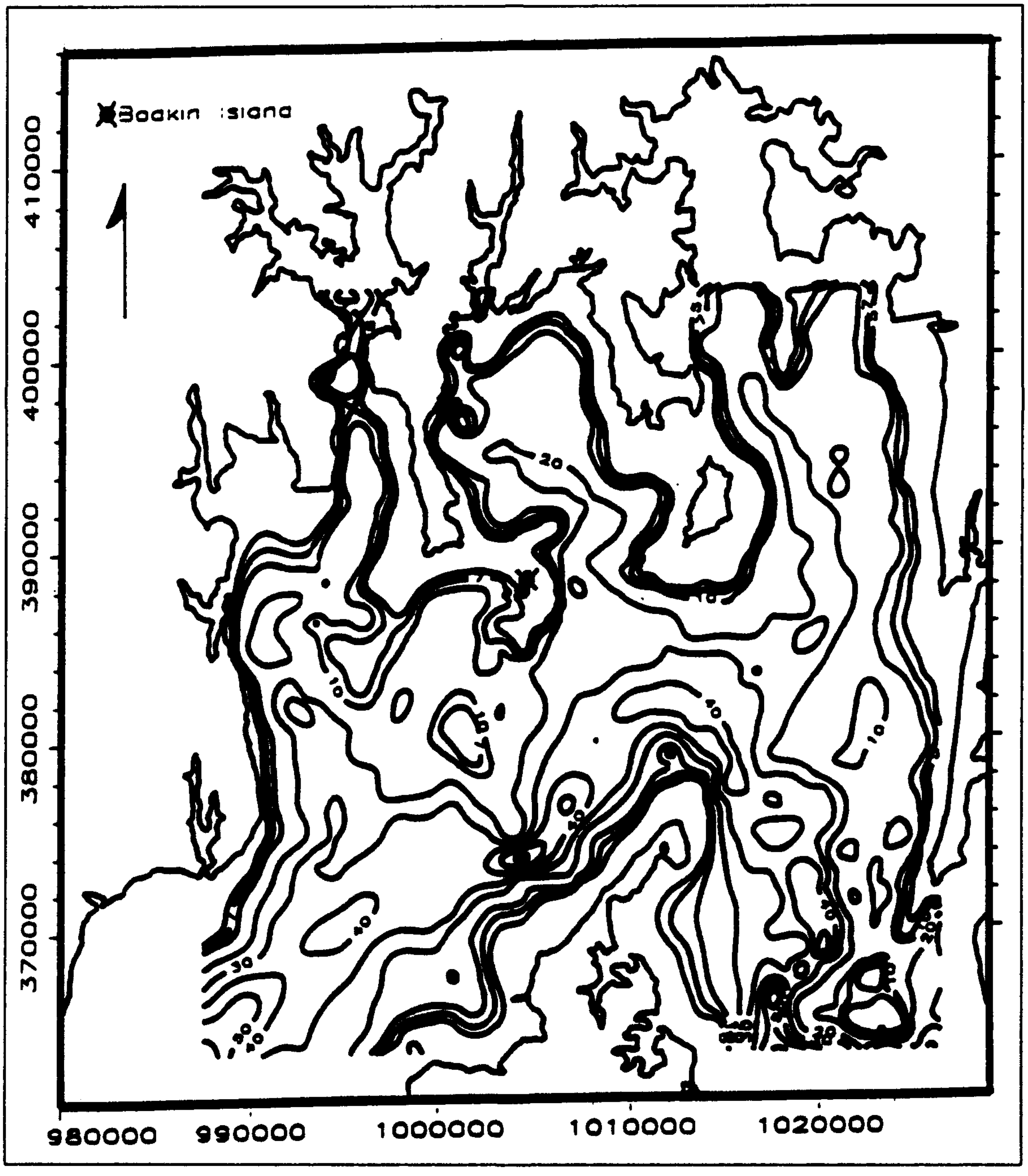


Figure 13. Contour map of NAB and HL bathymetry with surrounding land masses

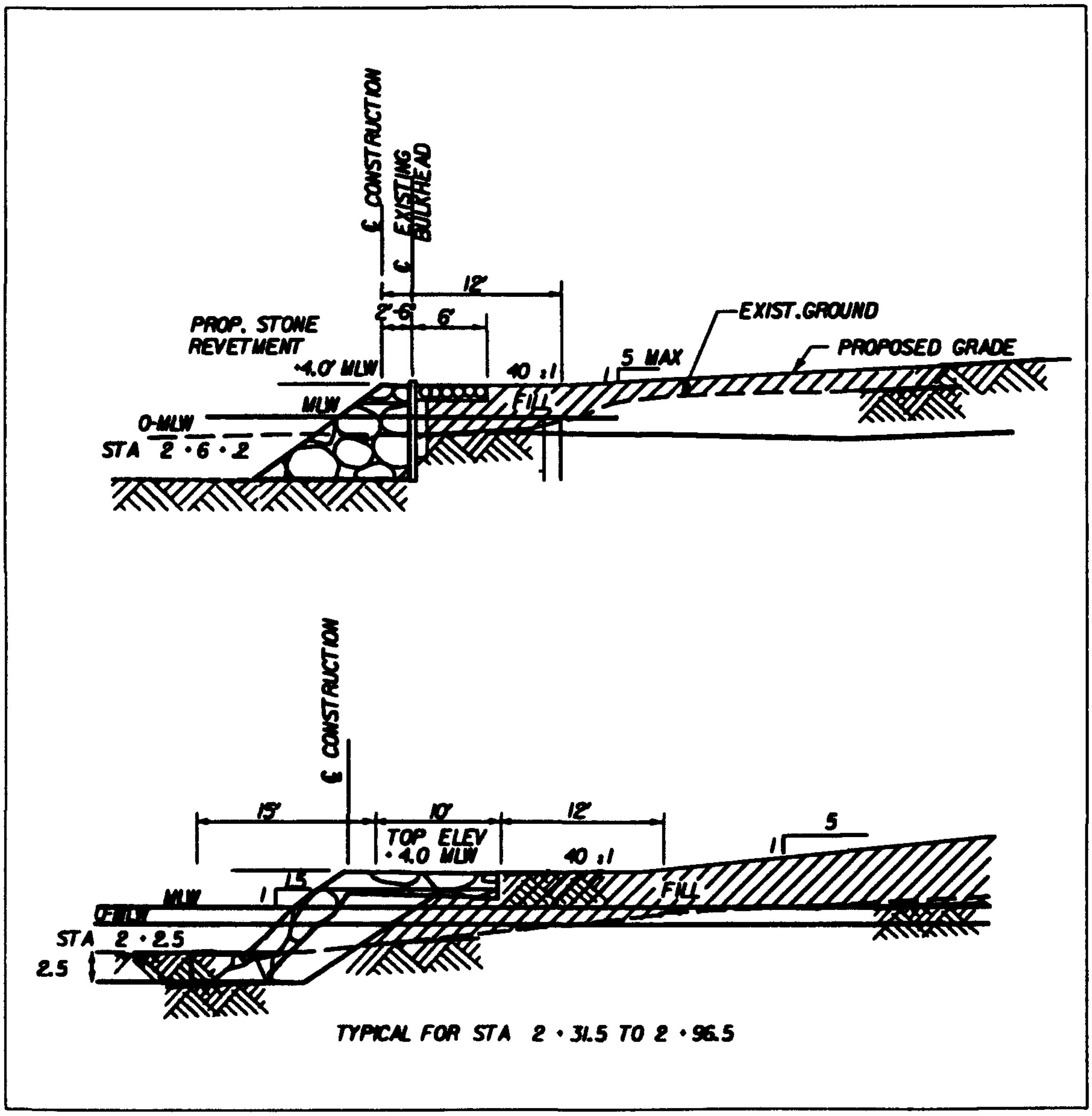


Figure 14. Existing structure specifications from 1984 repair of Bodkin Island

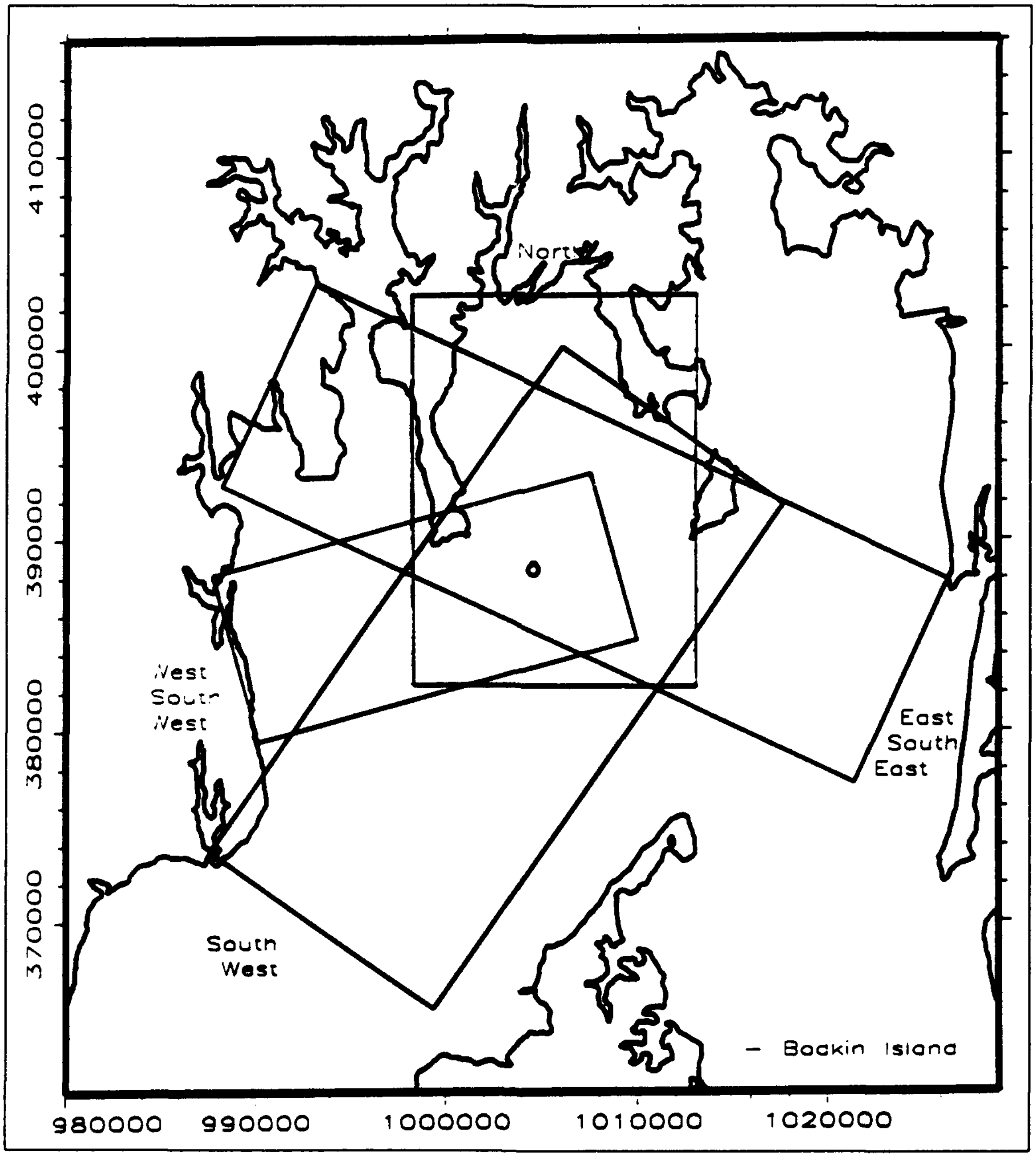


Figure 15. Boundary outlines for each grid used in wave analysis

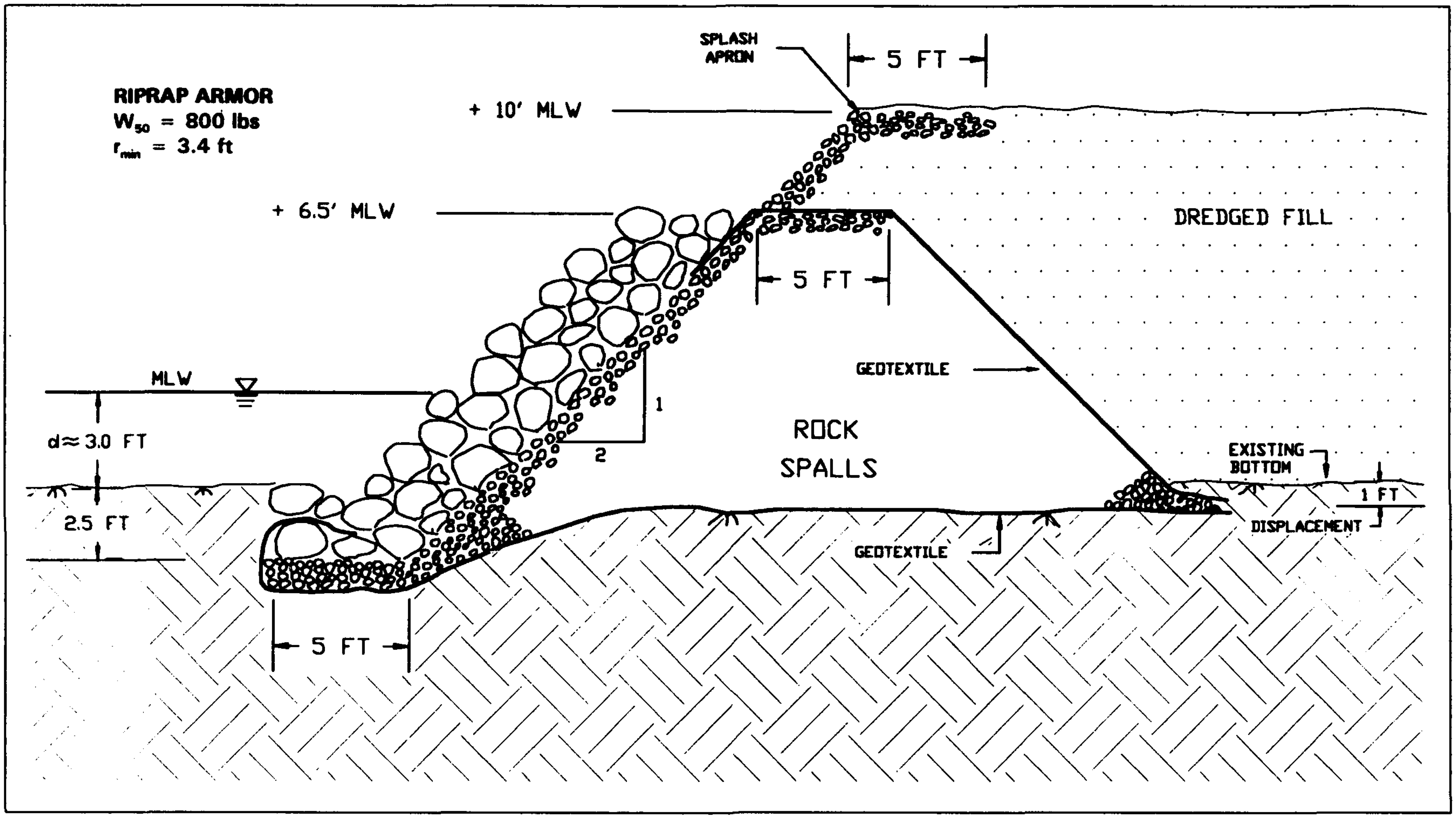


Figure 16. Southern cross section of containment dike and revetment

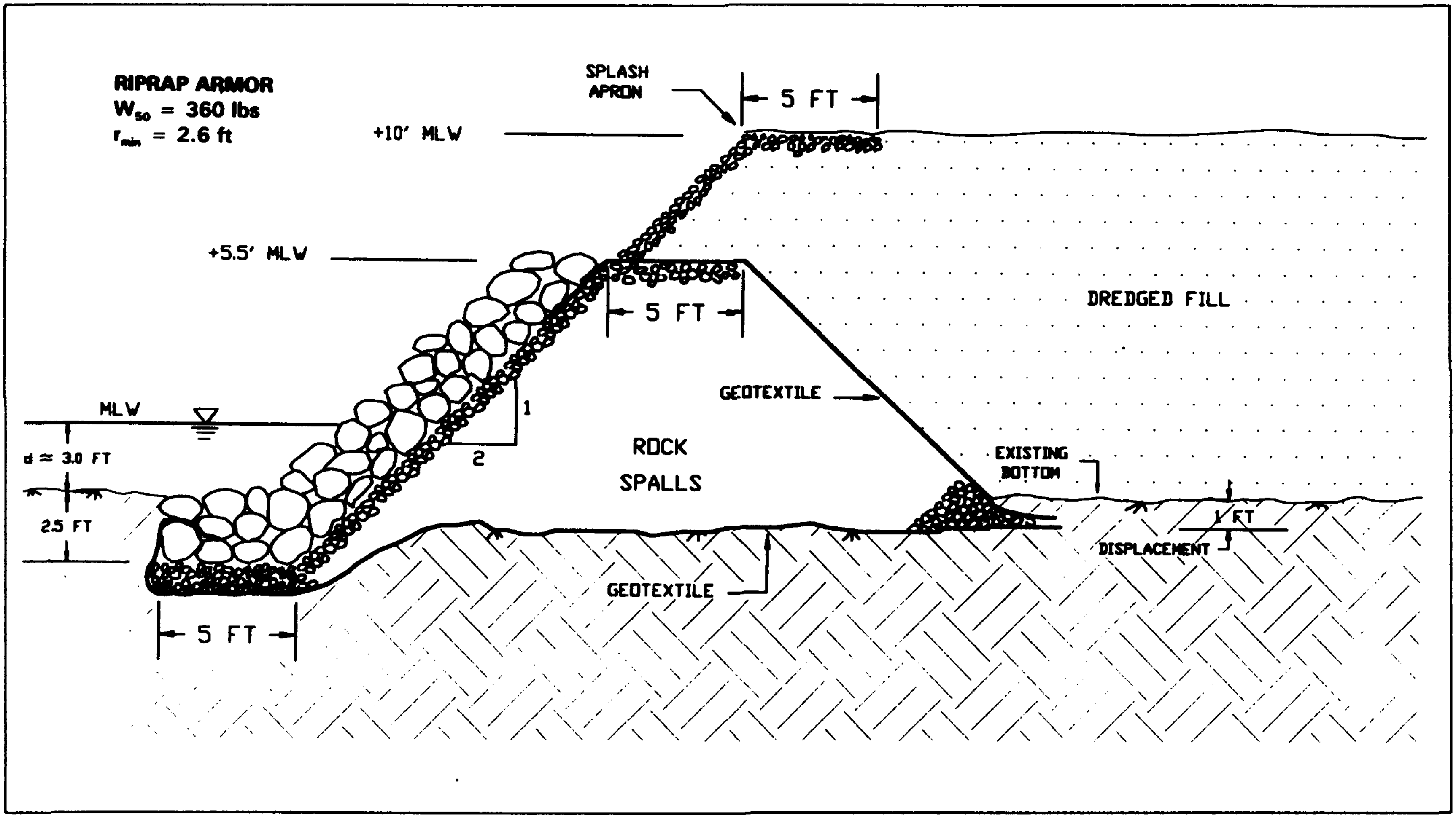


Figure 17. Northern cross section of containment dike and revetment

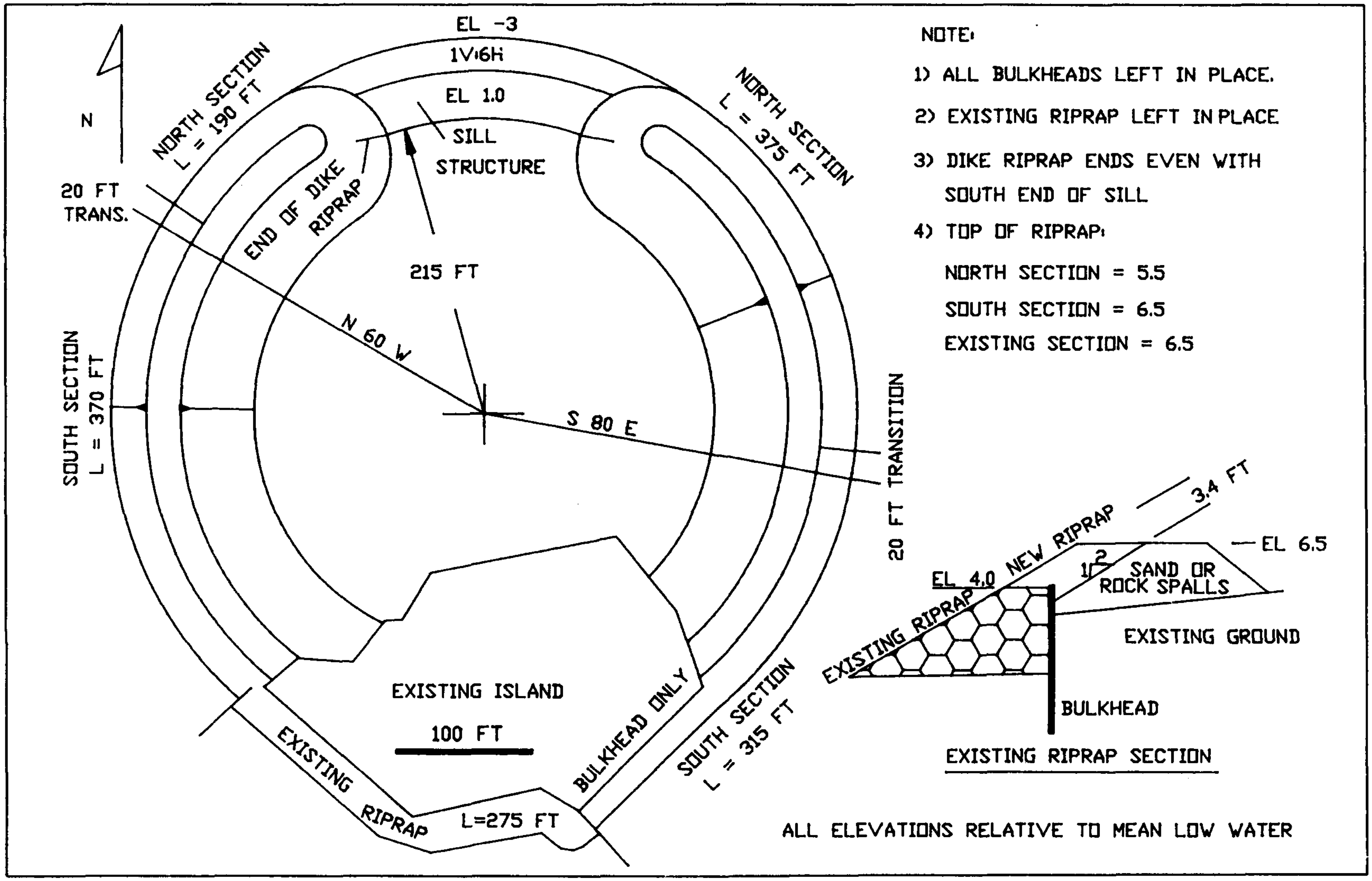


Figure 18. Riprap plan

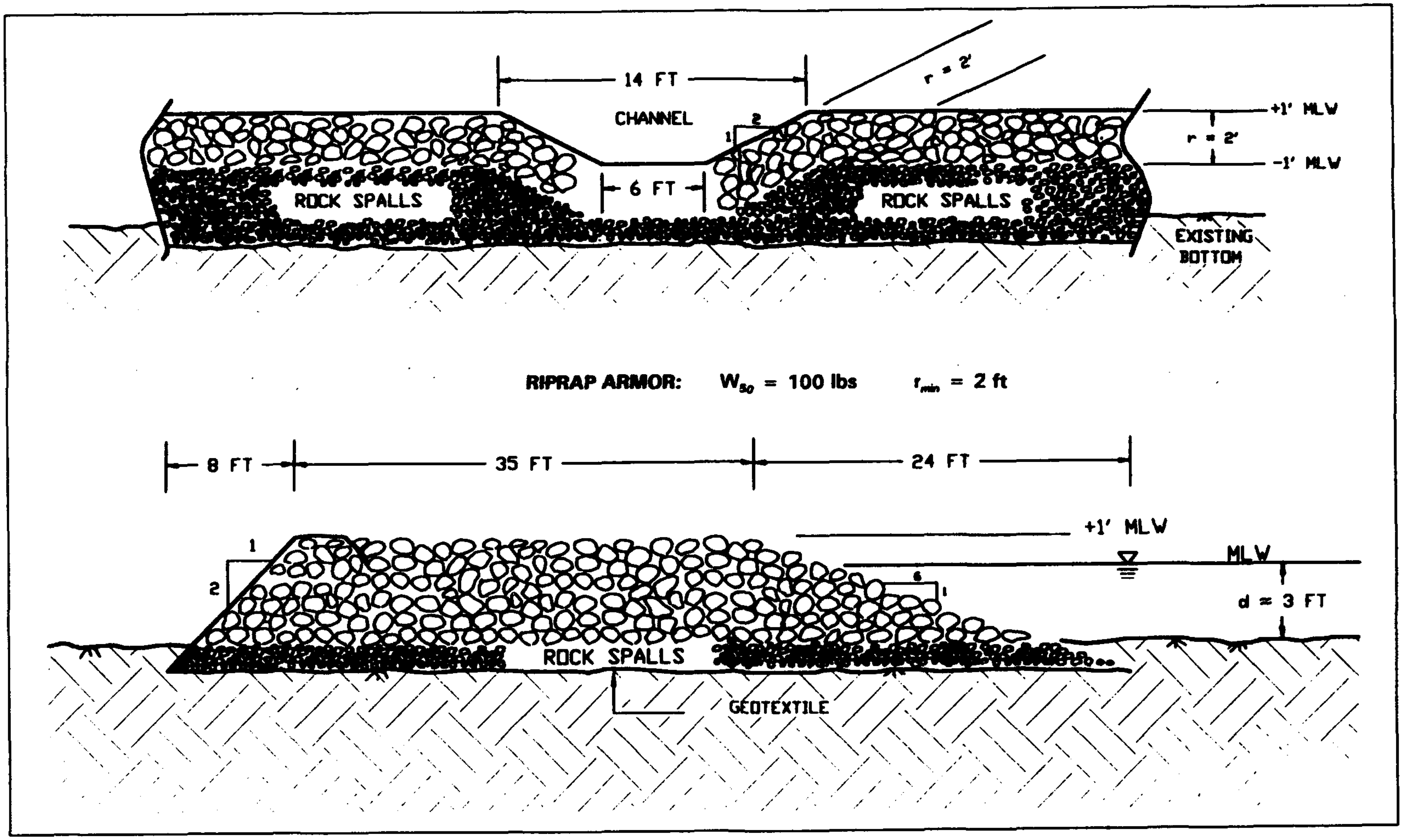


Figure 19. Cross sections of sill structure

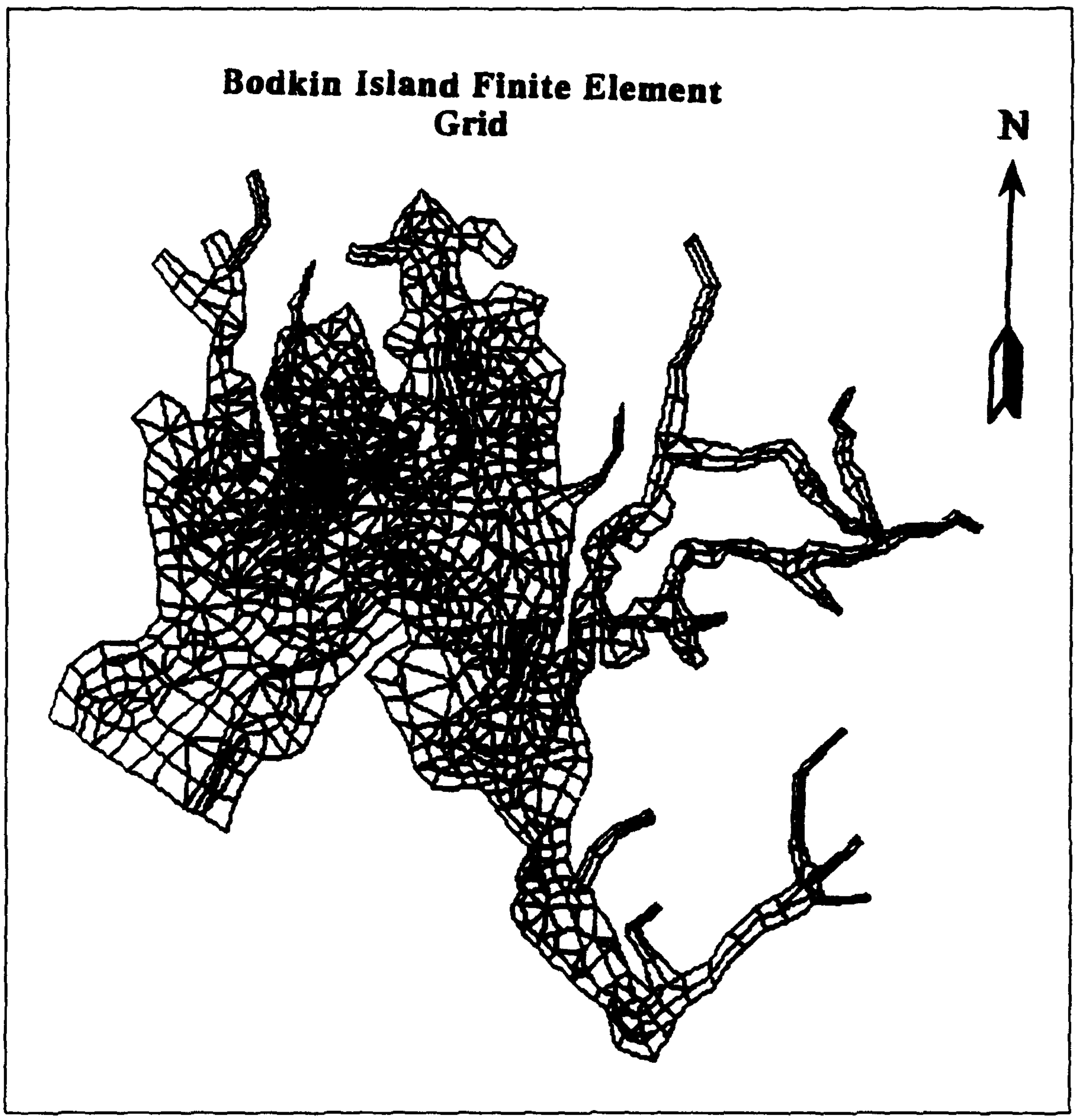


Figure 20. Finite element grid used for hydrodynamic model

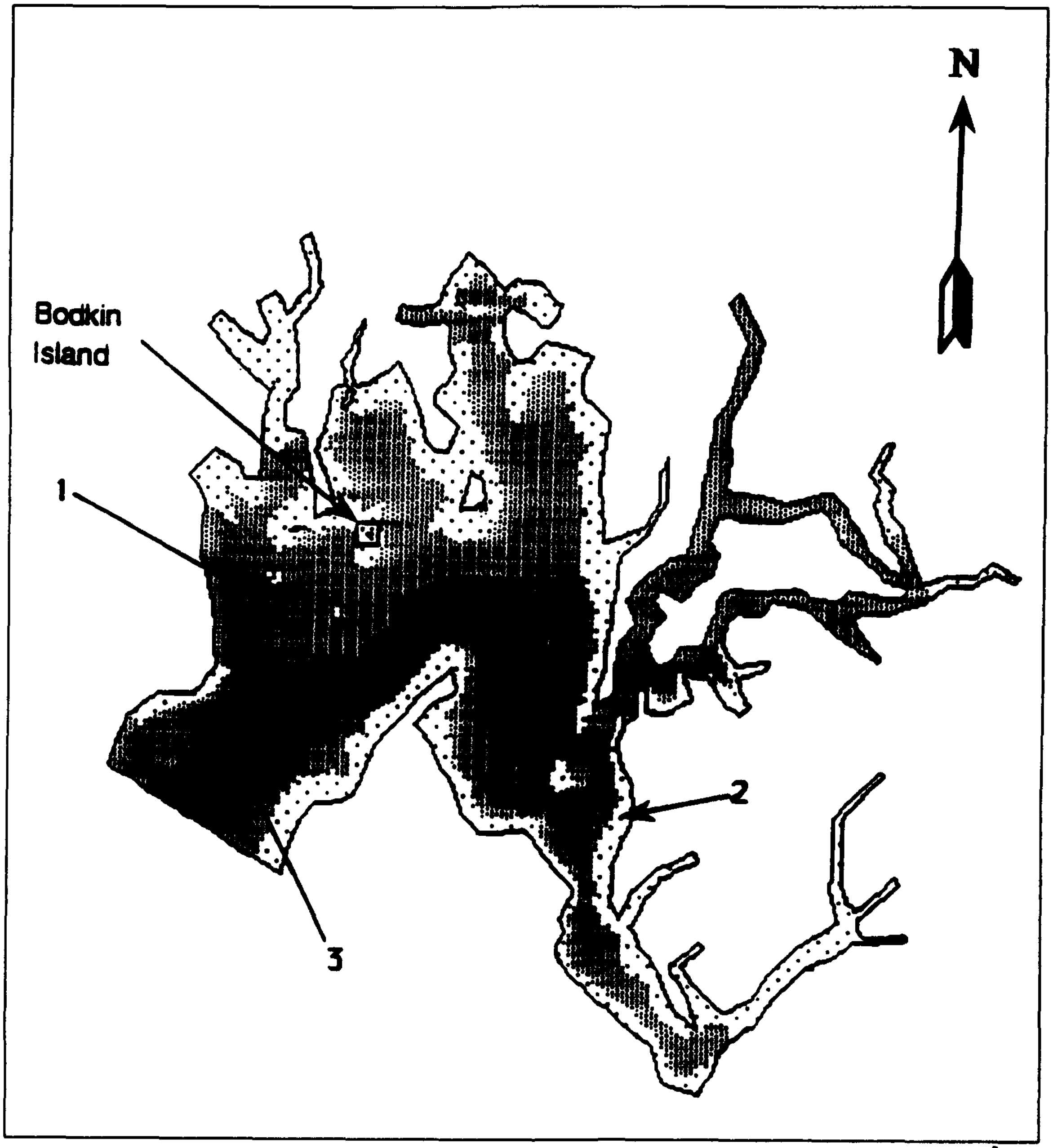


Figure 21. Hydraulic parameter type regions for hydrodynamic model

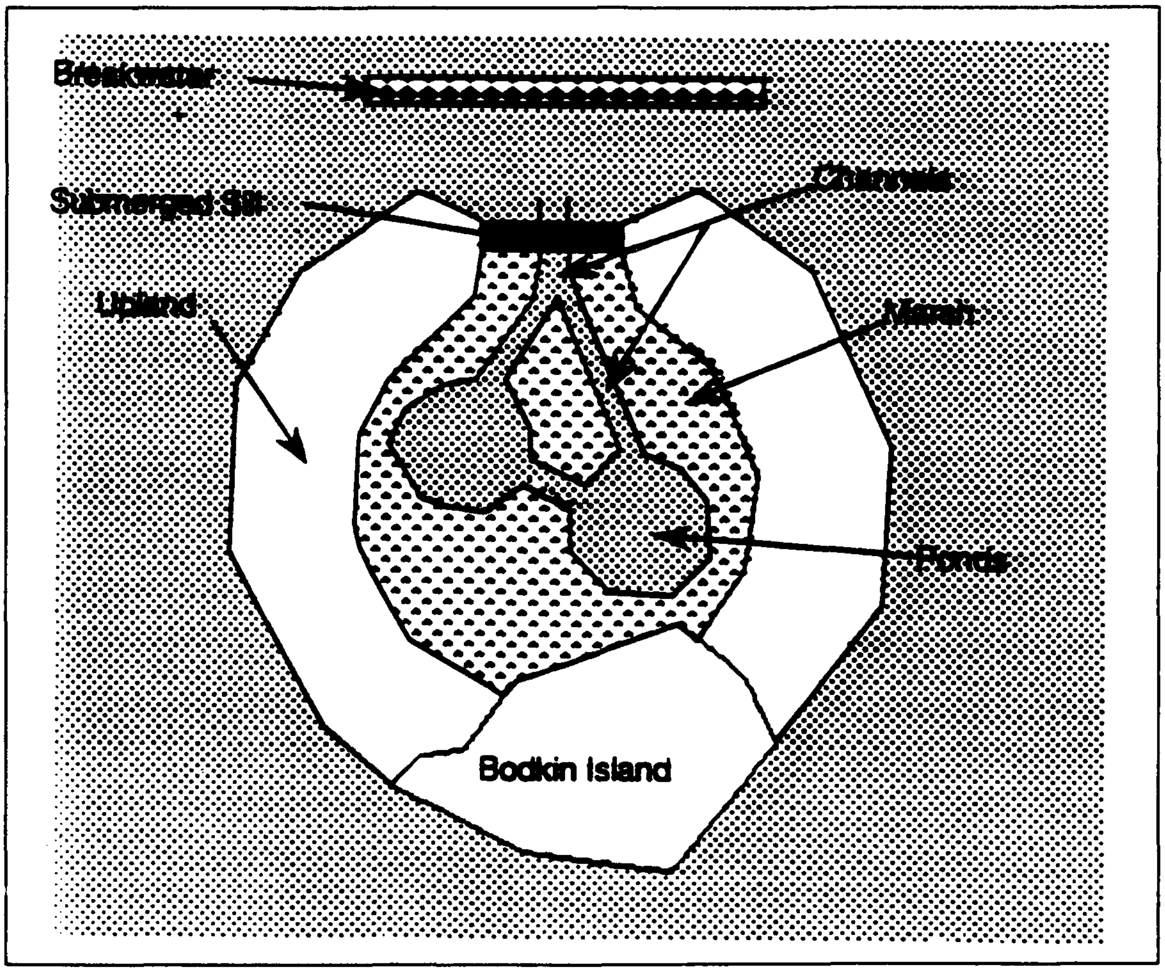


Figure 22. Schematic of proposed improvements used in numerical study (breakwater not in recommended plan)

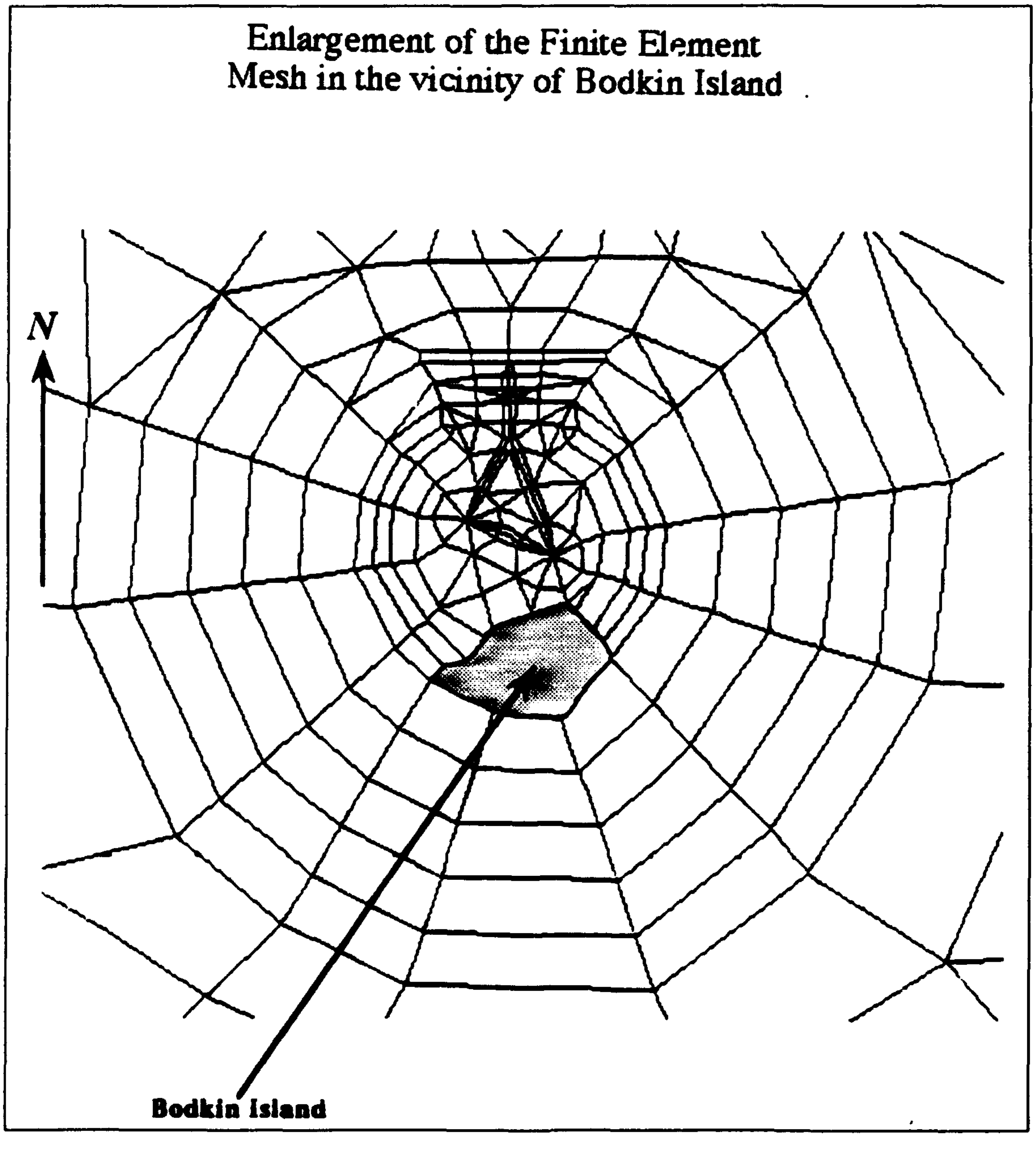


Figure 23. Finite element mesh in the vicinity of Bodkin Island

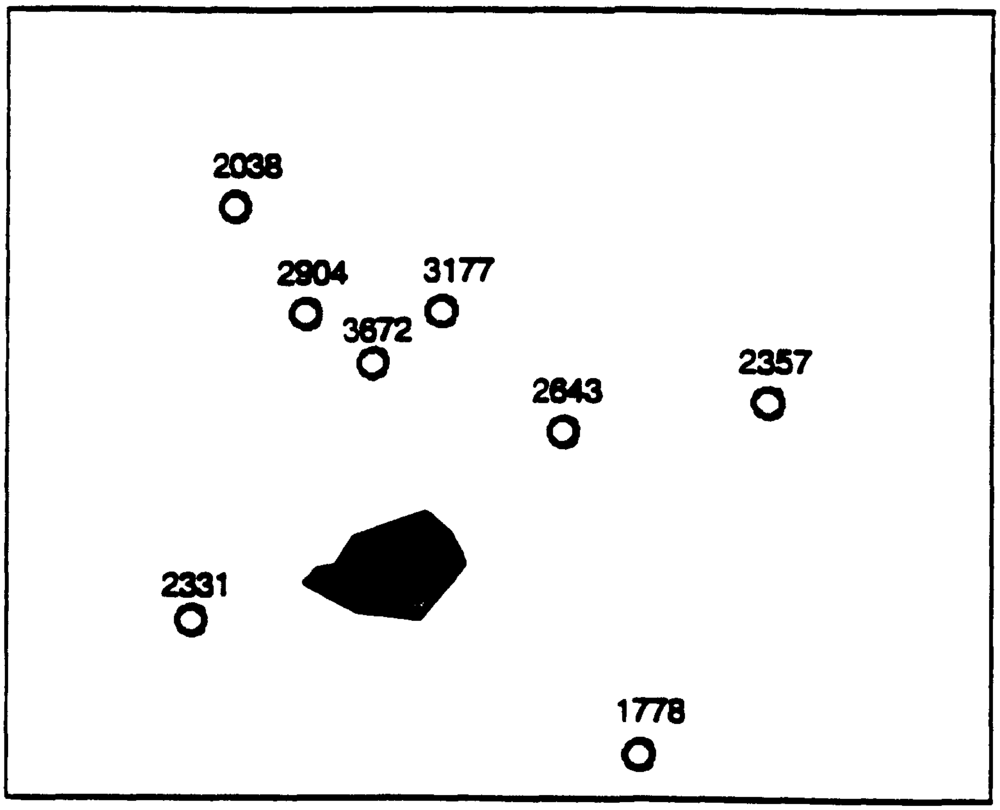


Figure 24. Selected node locations for base and plan comparisons

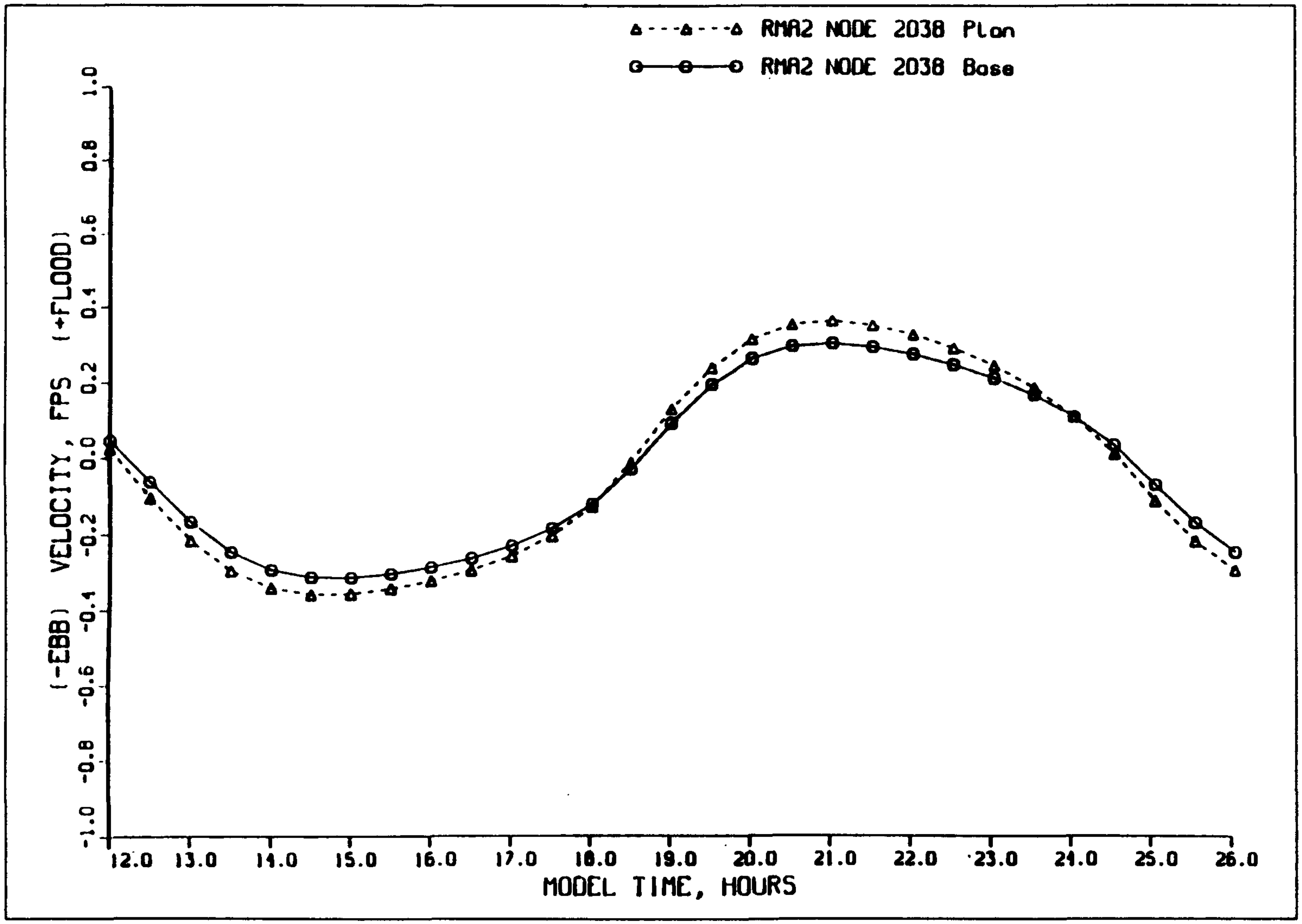


Figure 25. Base versus plan velocities for Node 2038

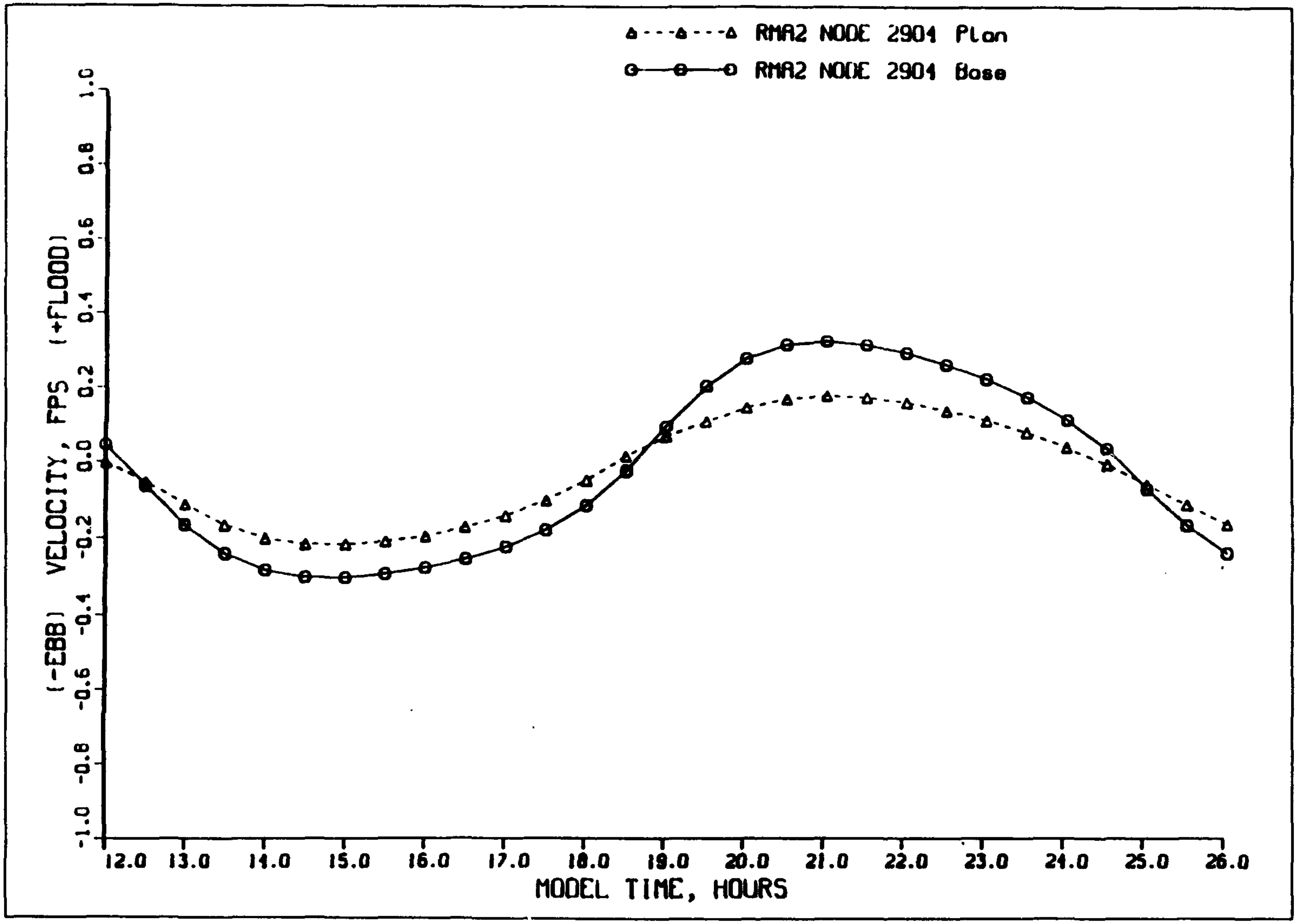


Figure 26. Base versus plan velocities for Node 2904

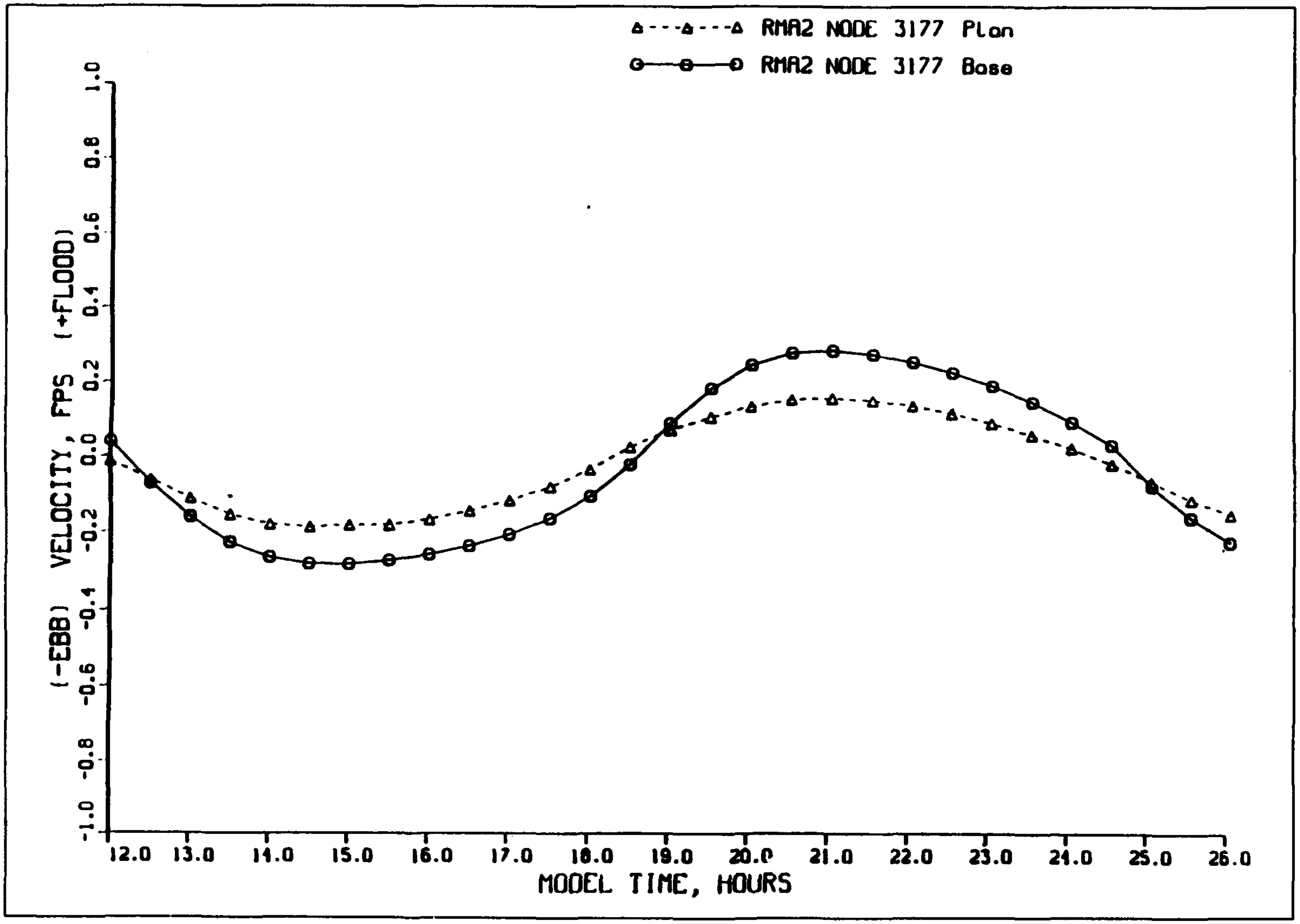


Figure 27. Base versus plan velocities for Node 3177

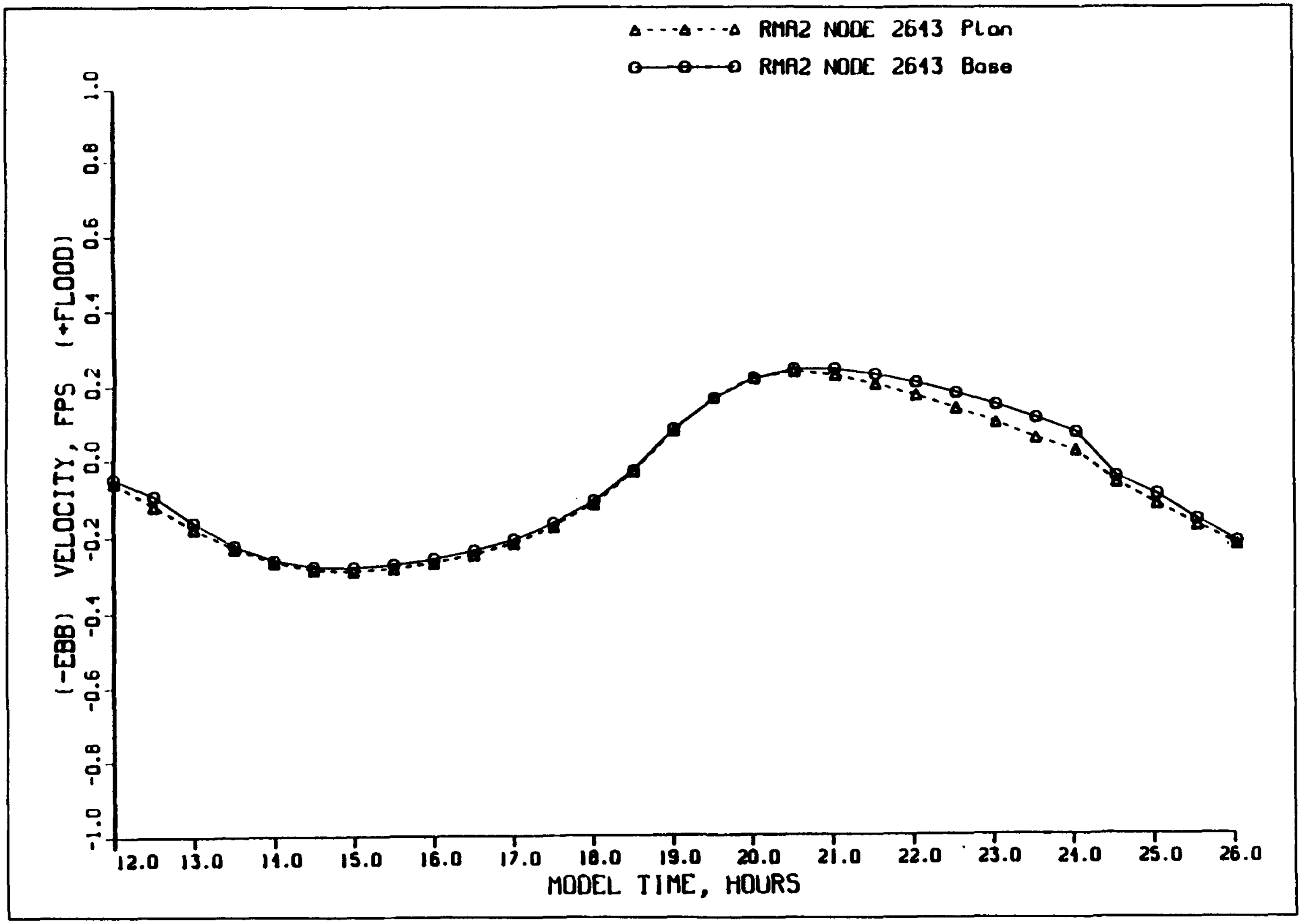


Figure 28. Base versus plan velocities for Node 2643

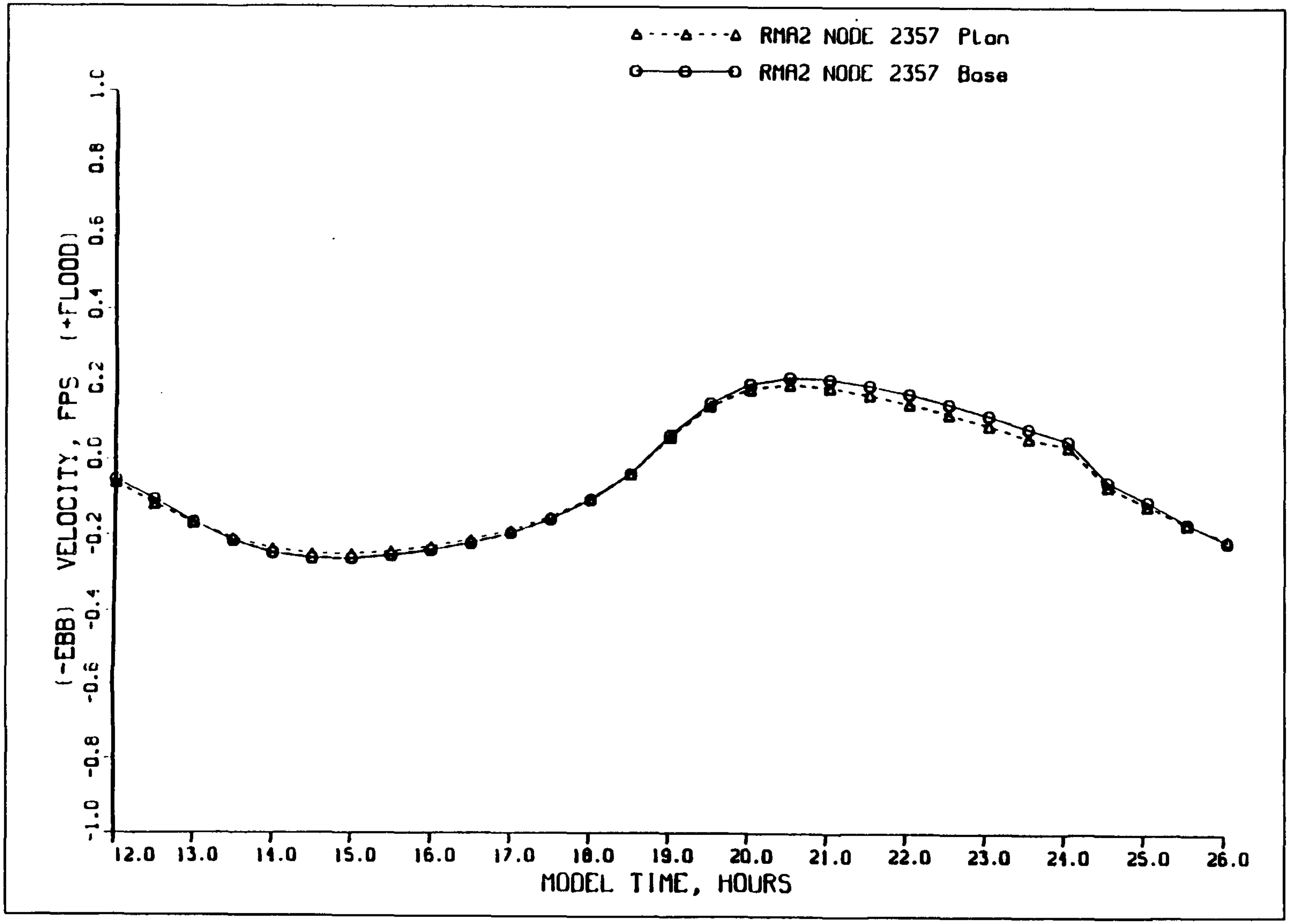


Figure 29. Base versus plan velocities for Node 2357

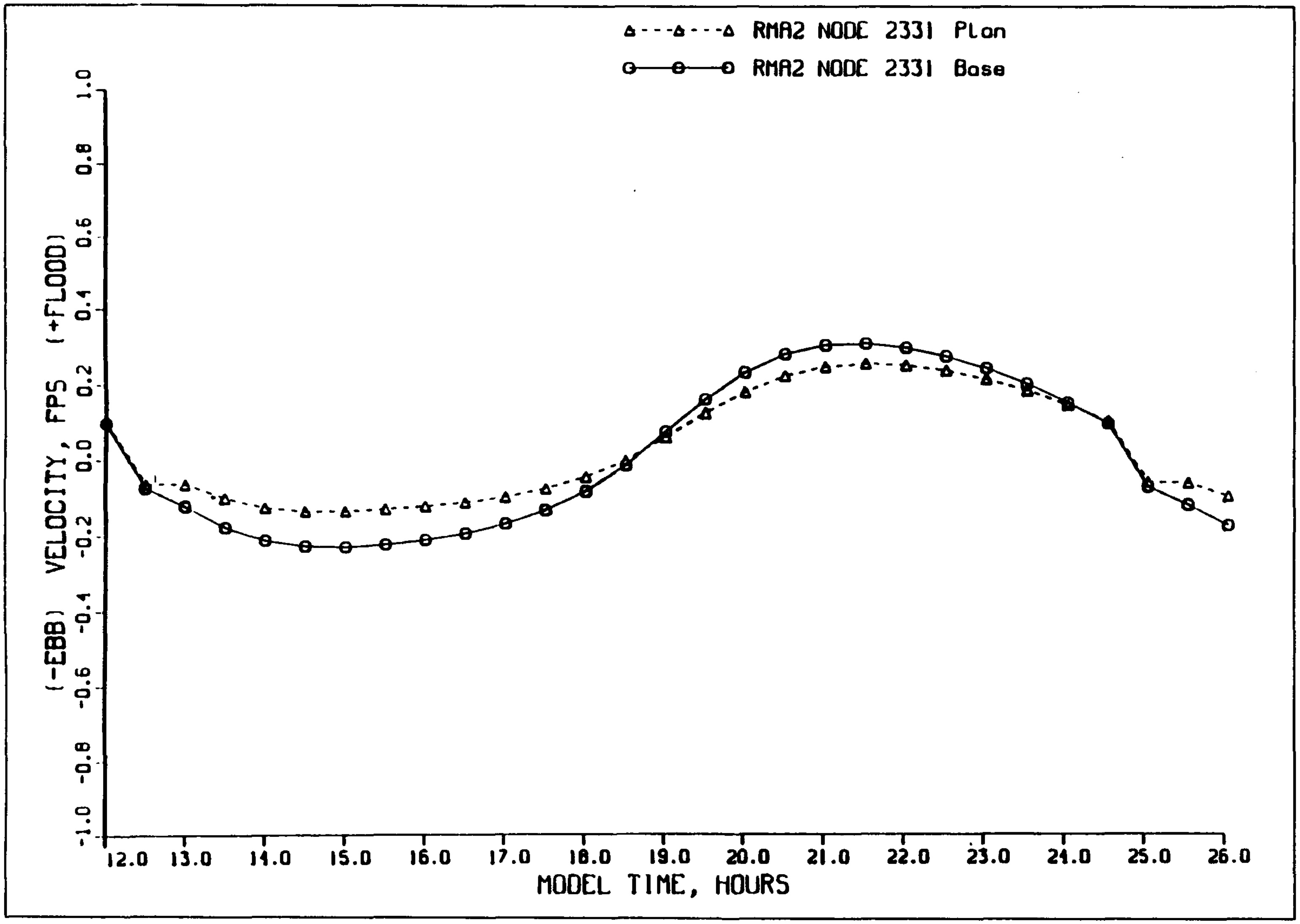


Figure 30. Base versus plan velocities for Node 2331

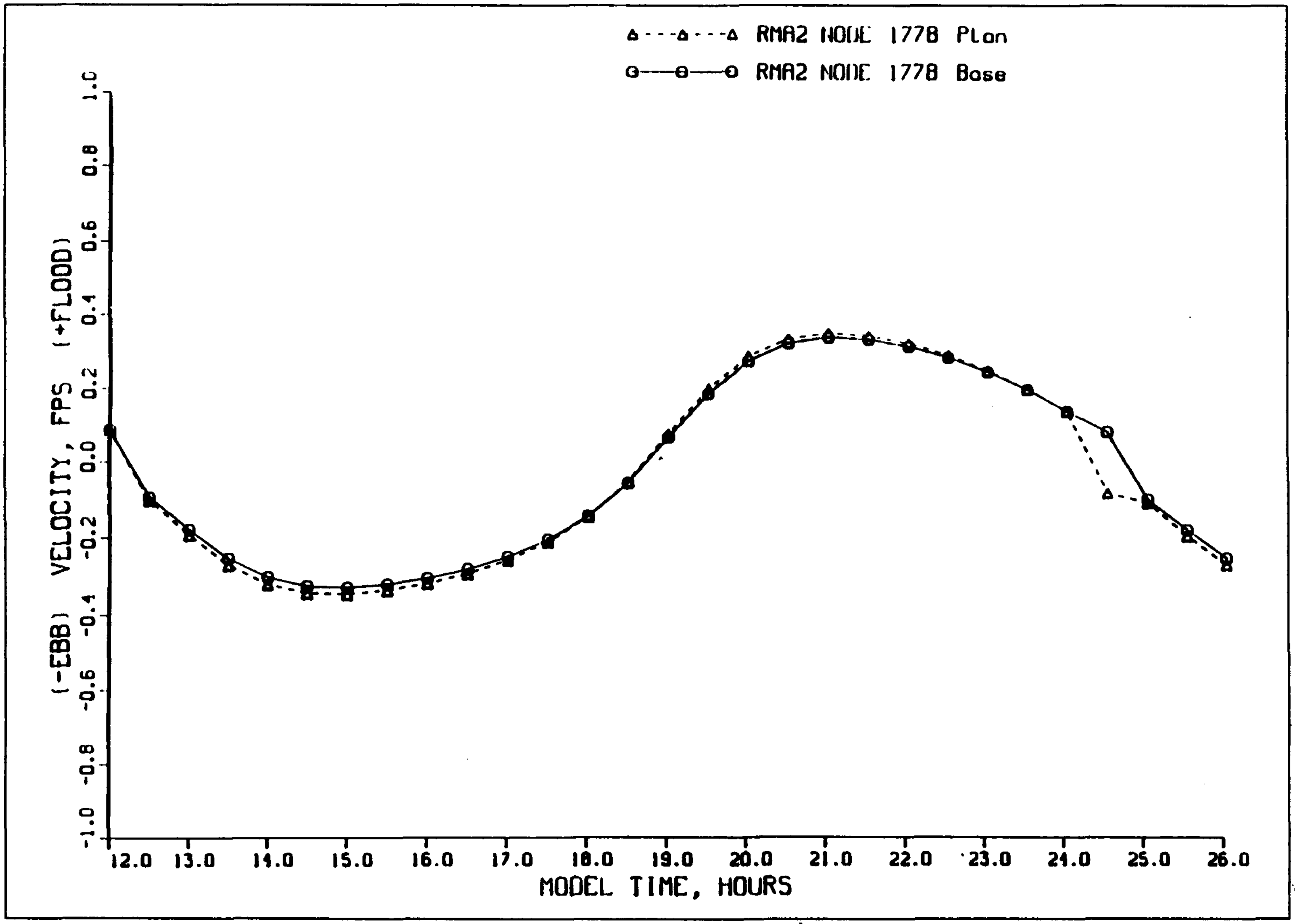


Figure 31. Base versus plan velocities for Node 1778

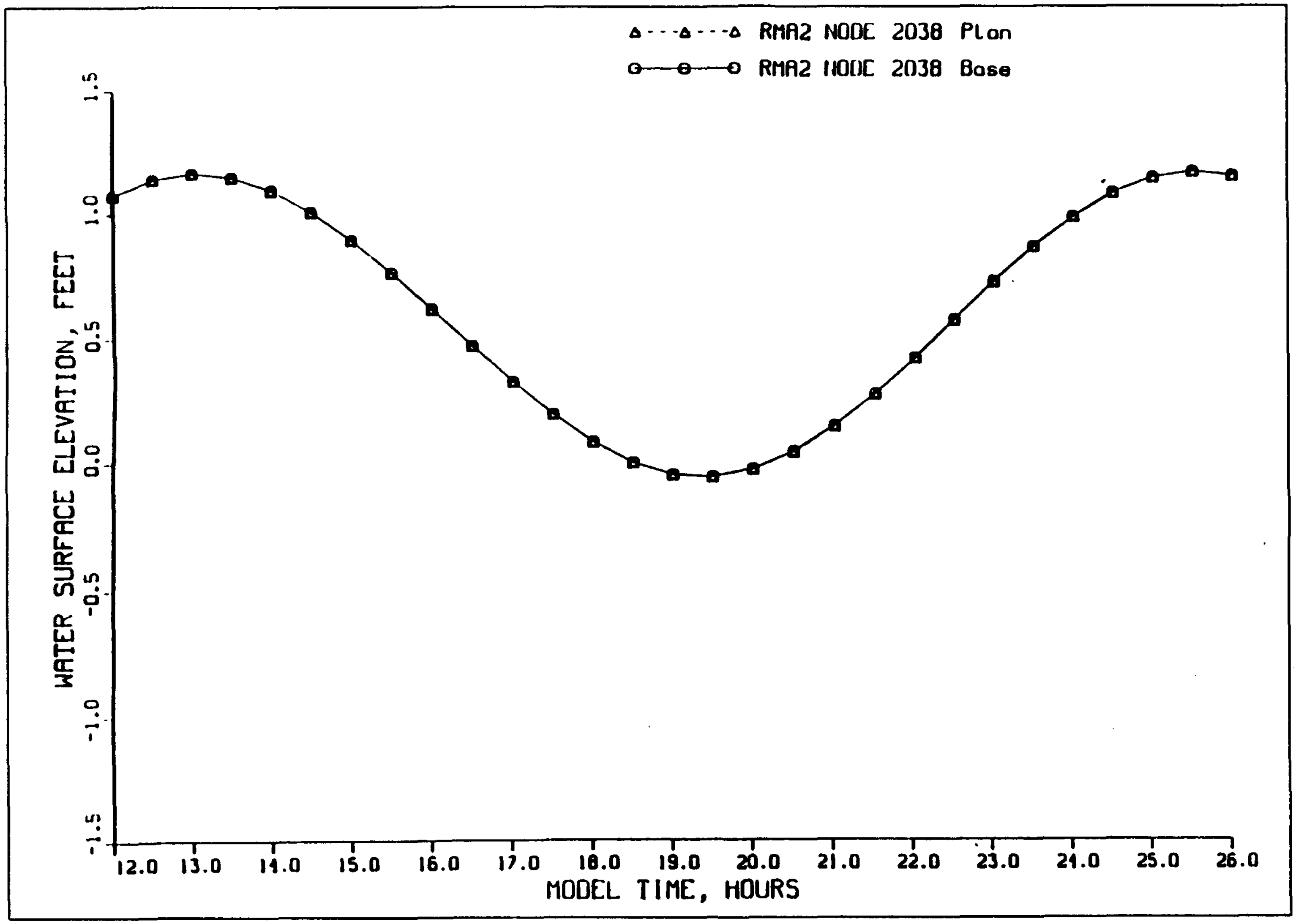


Figure 32. Base versus plan water elevations for Node 2038

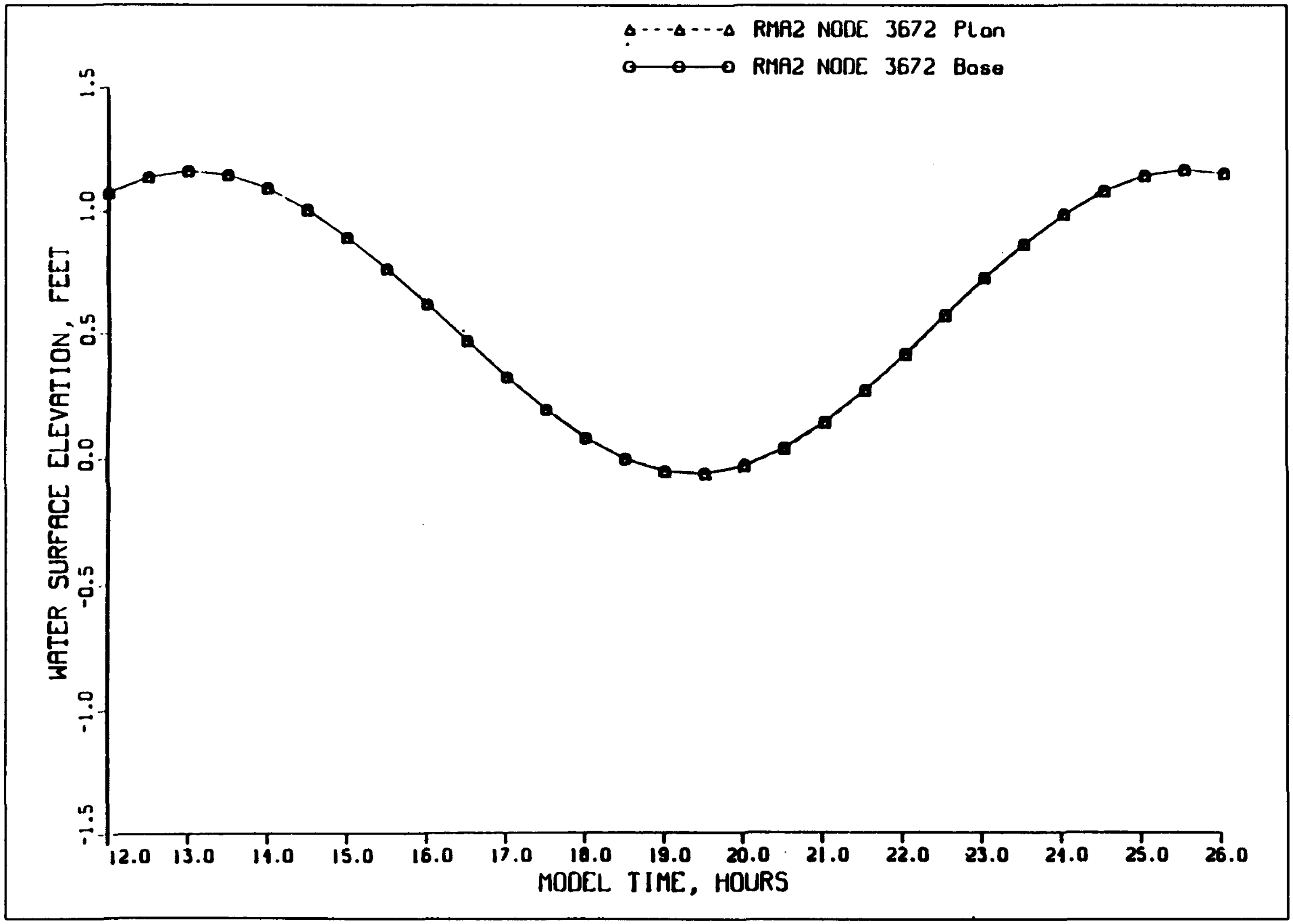


Figure 33. Base versus plan water elevations for Node 3672

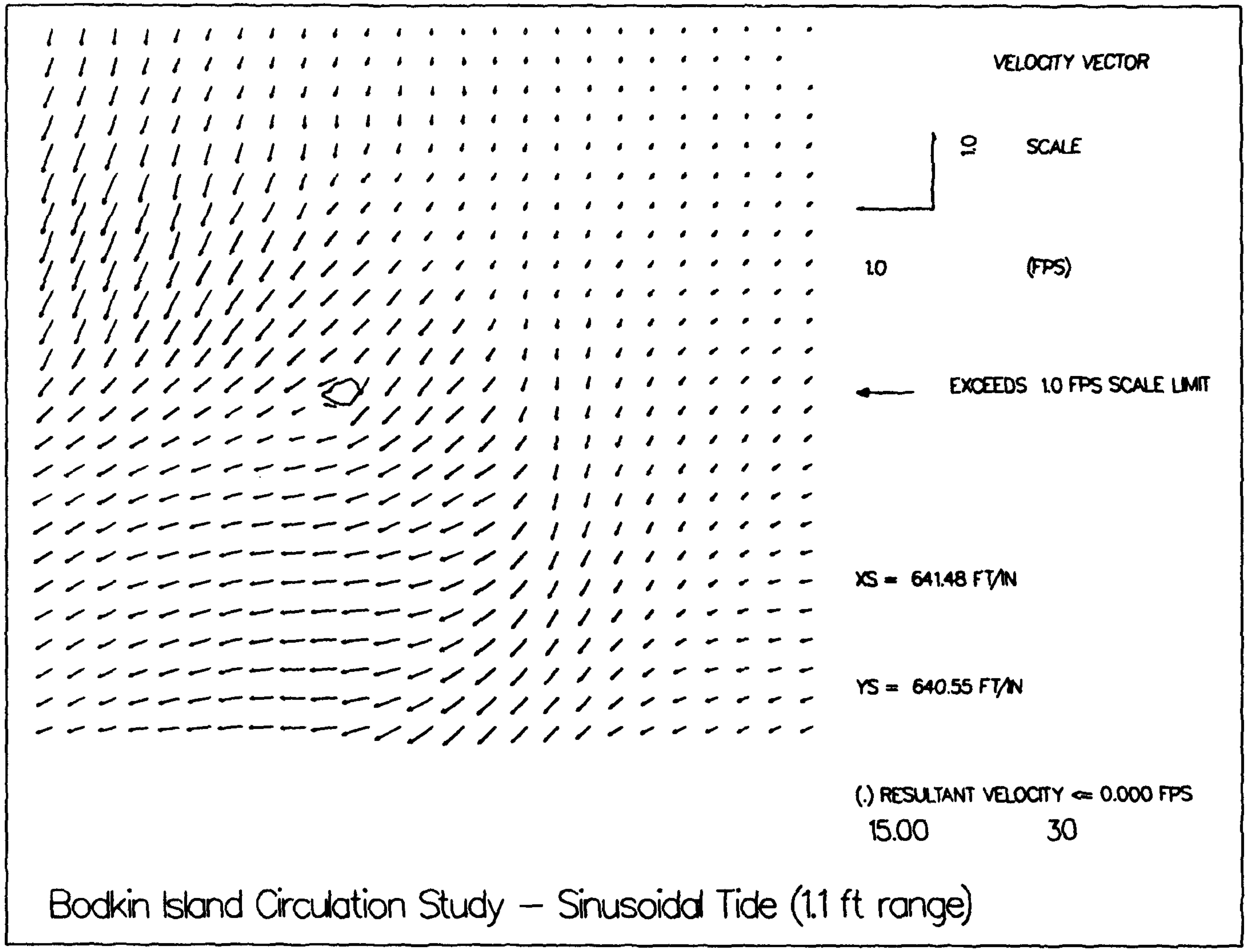


Figure 34. Velocity vectors for base conditions near maximum ebb

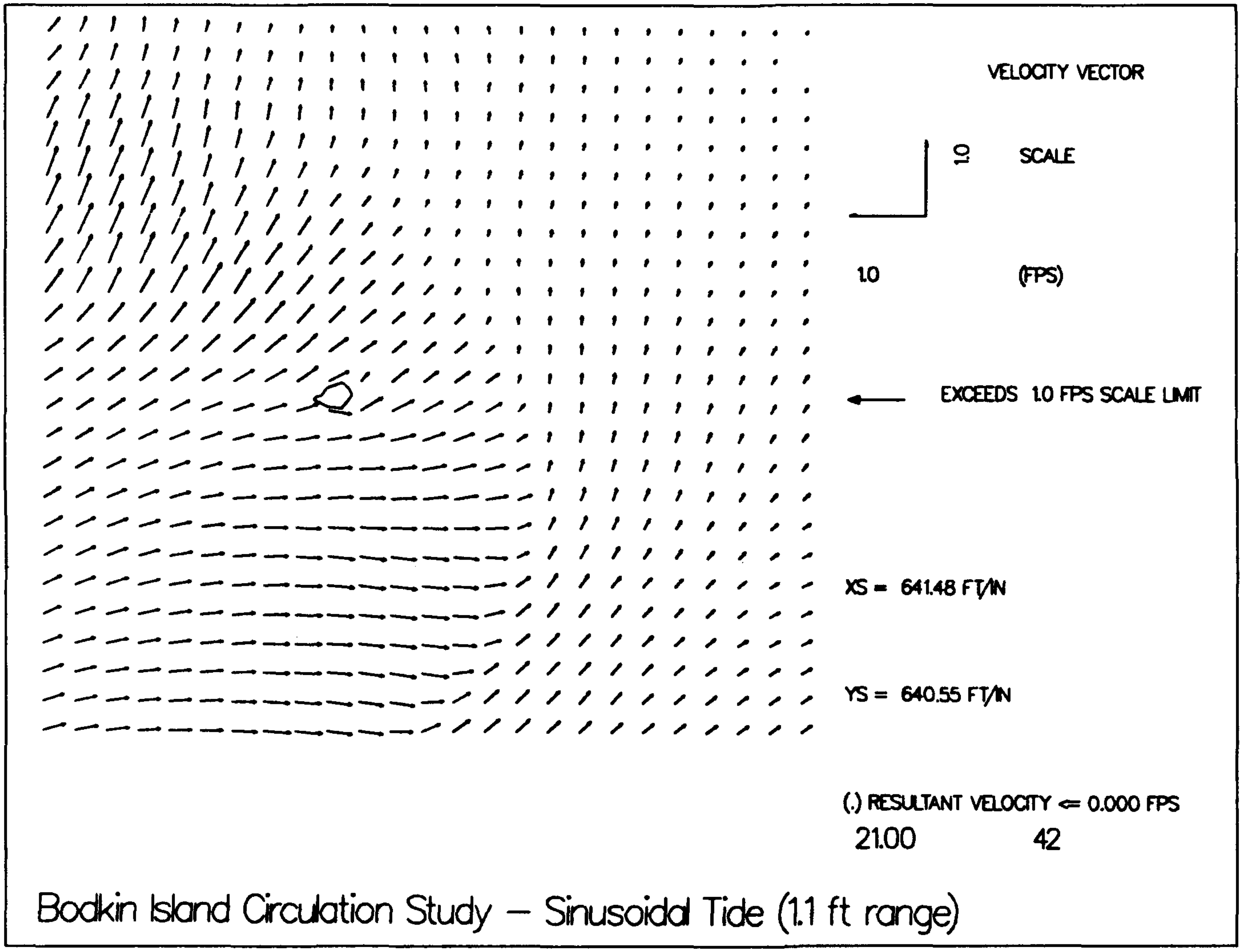


Figure 35. Velocity vectors for base conditions near maximum flood

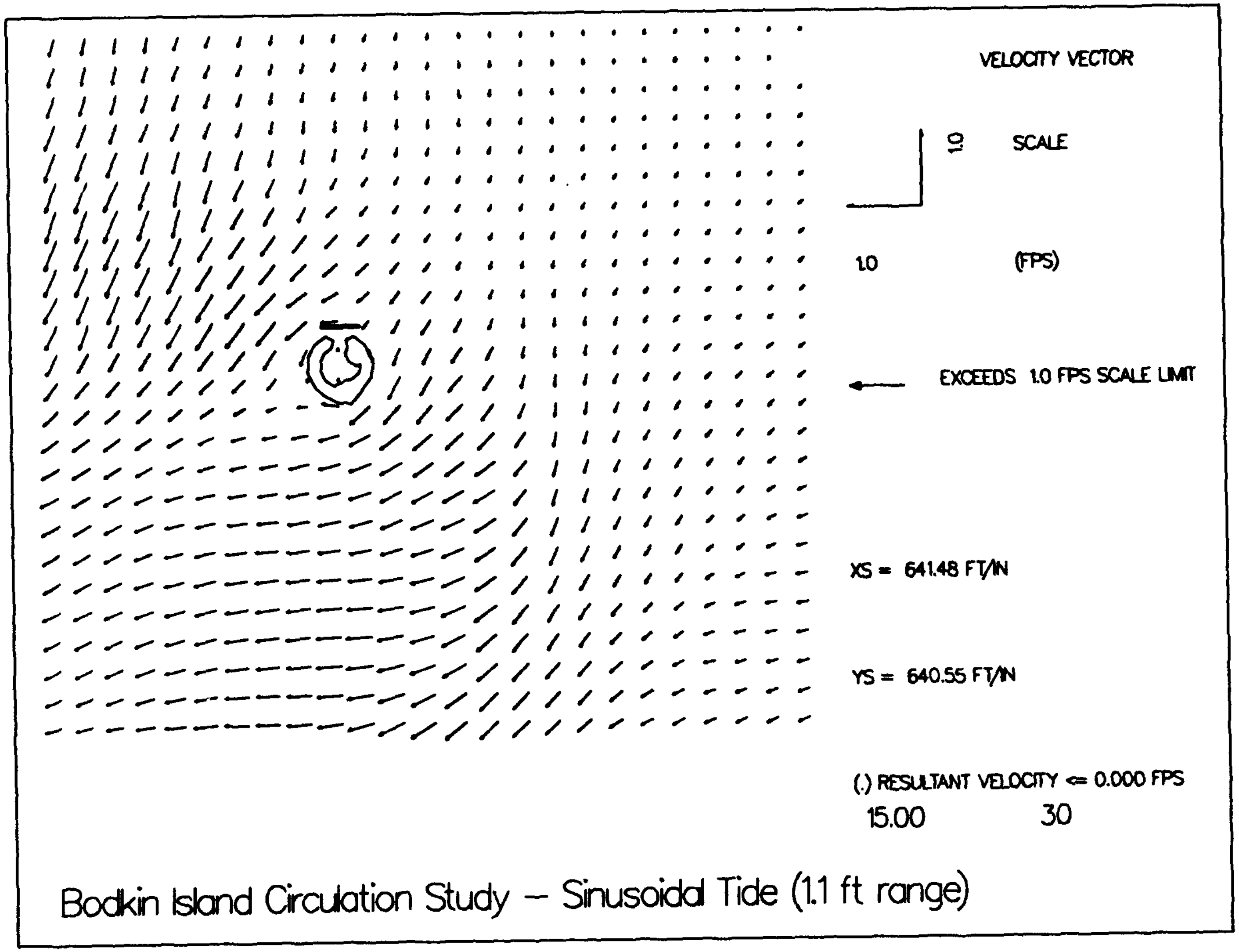


Figure 36. Velocity vectors for plan conditions near maximum ebb

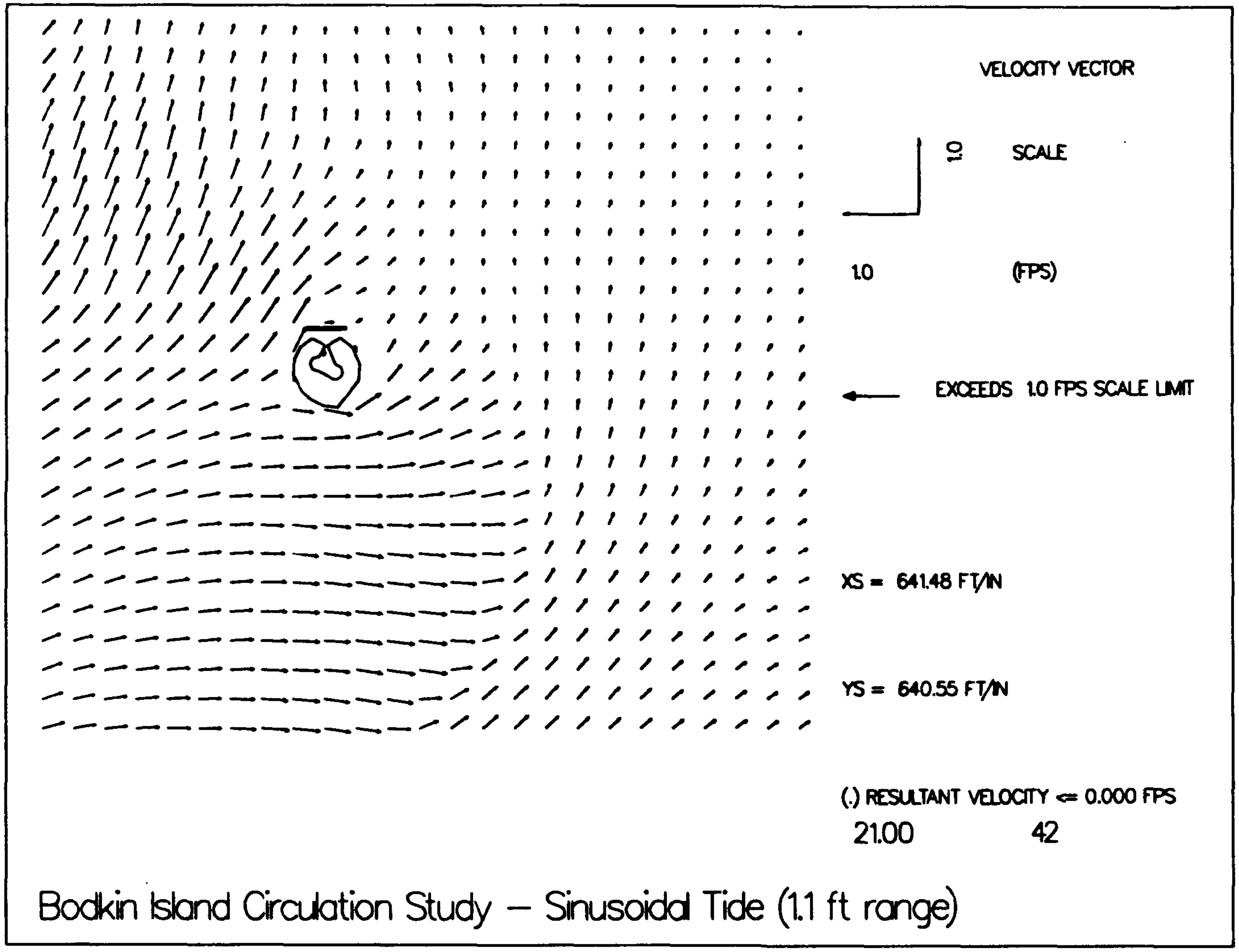


Figure 37. Velocity vectors for plan conditions near maximum flood

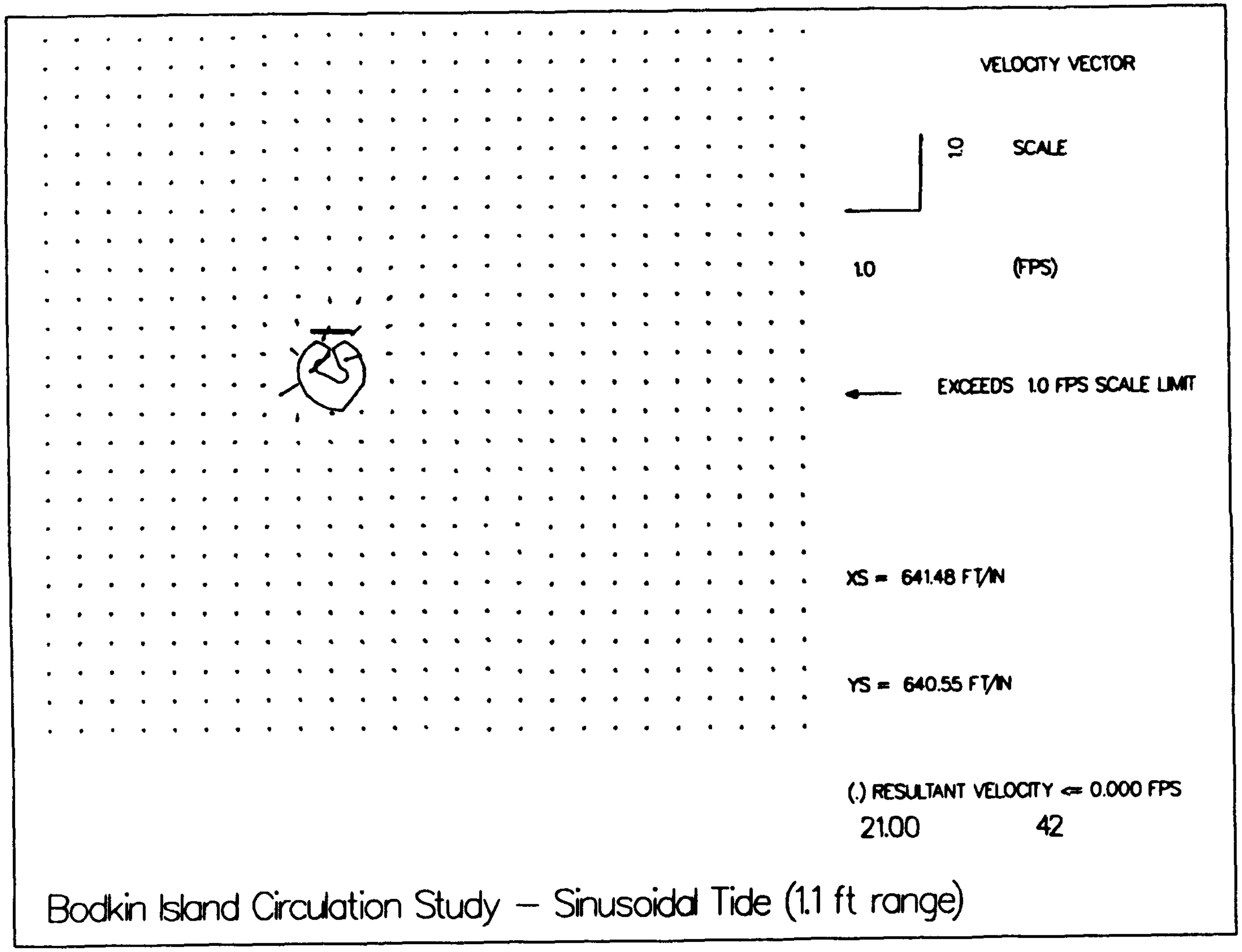


Figure 38. Velocity vector differences, base versus plan, ebb

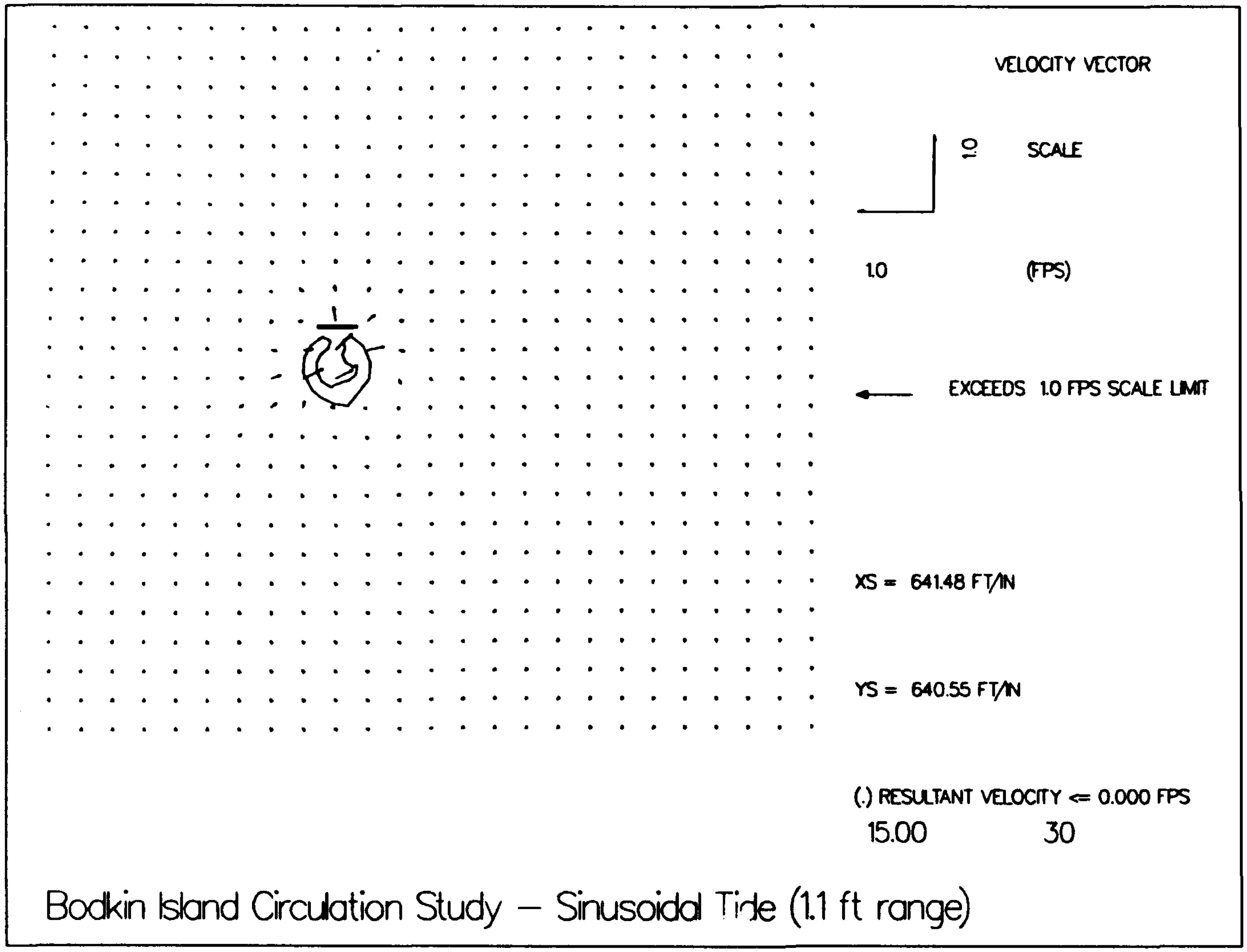


Figure 39. Velocity vector differences, base versus plan, flood

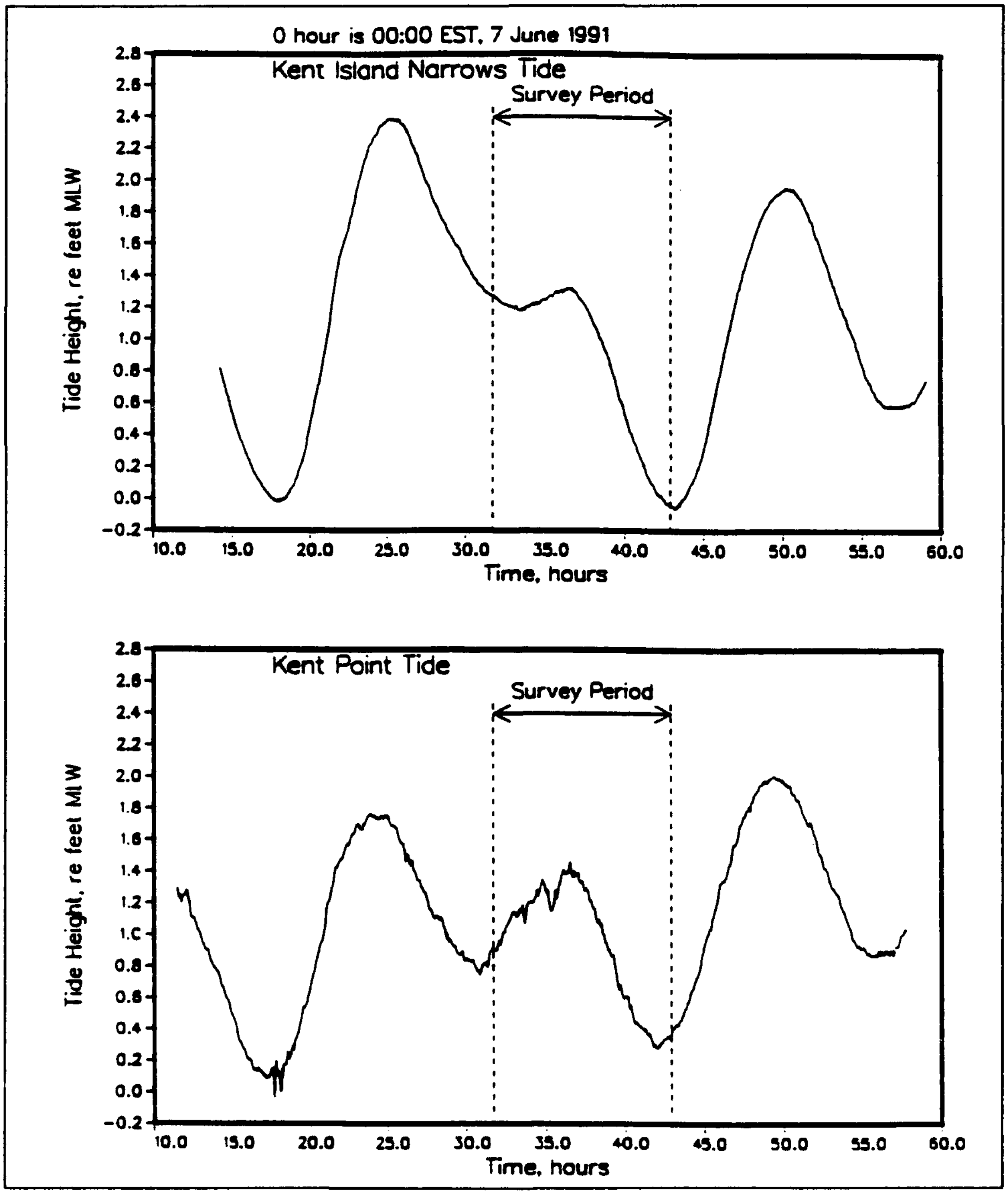


Figure 40. Field tide, 7-9 June 1991

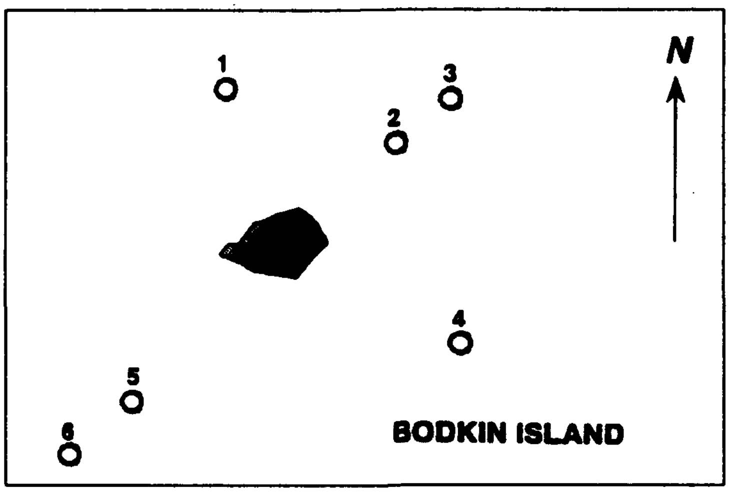


Figure 41. Field station locations, 8 June 1991

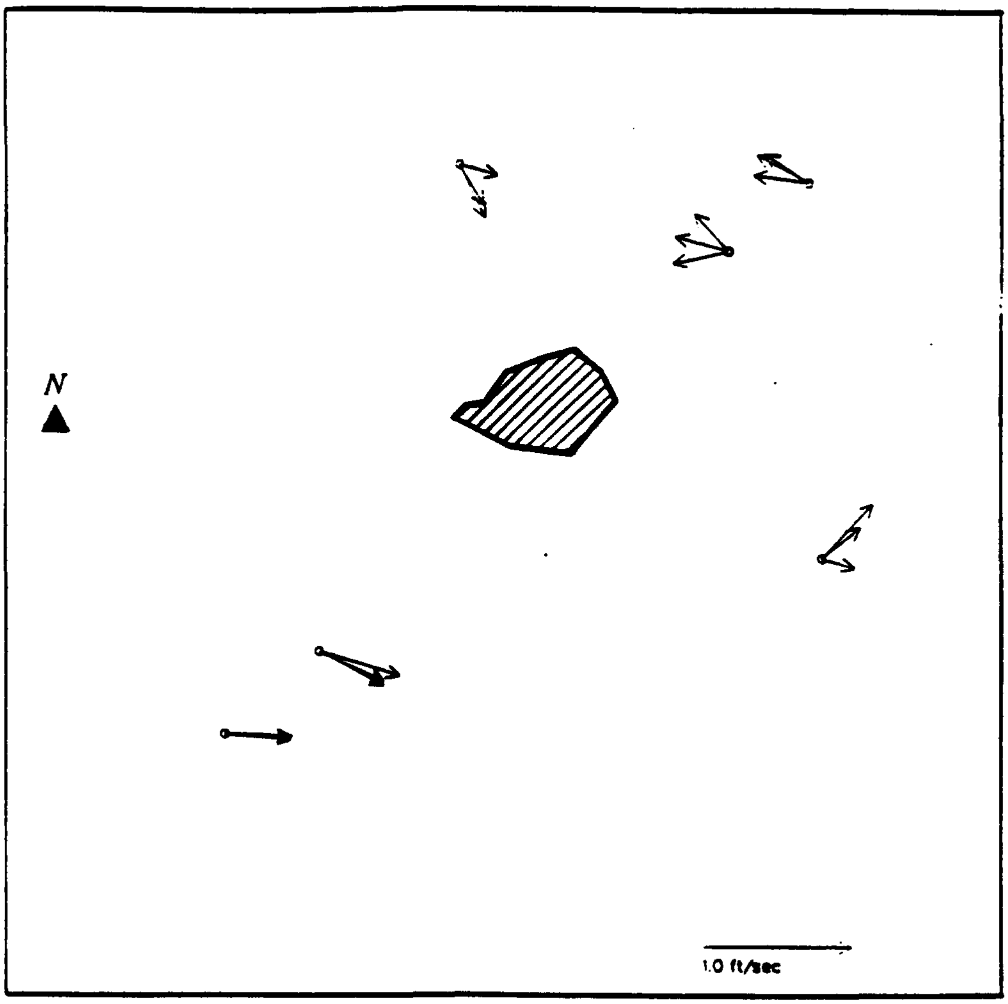


Figure 42. Velocity vectors, 07:43 to 08:11 EST, 8 June 1991

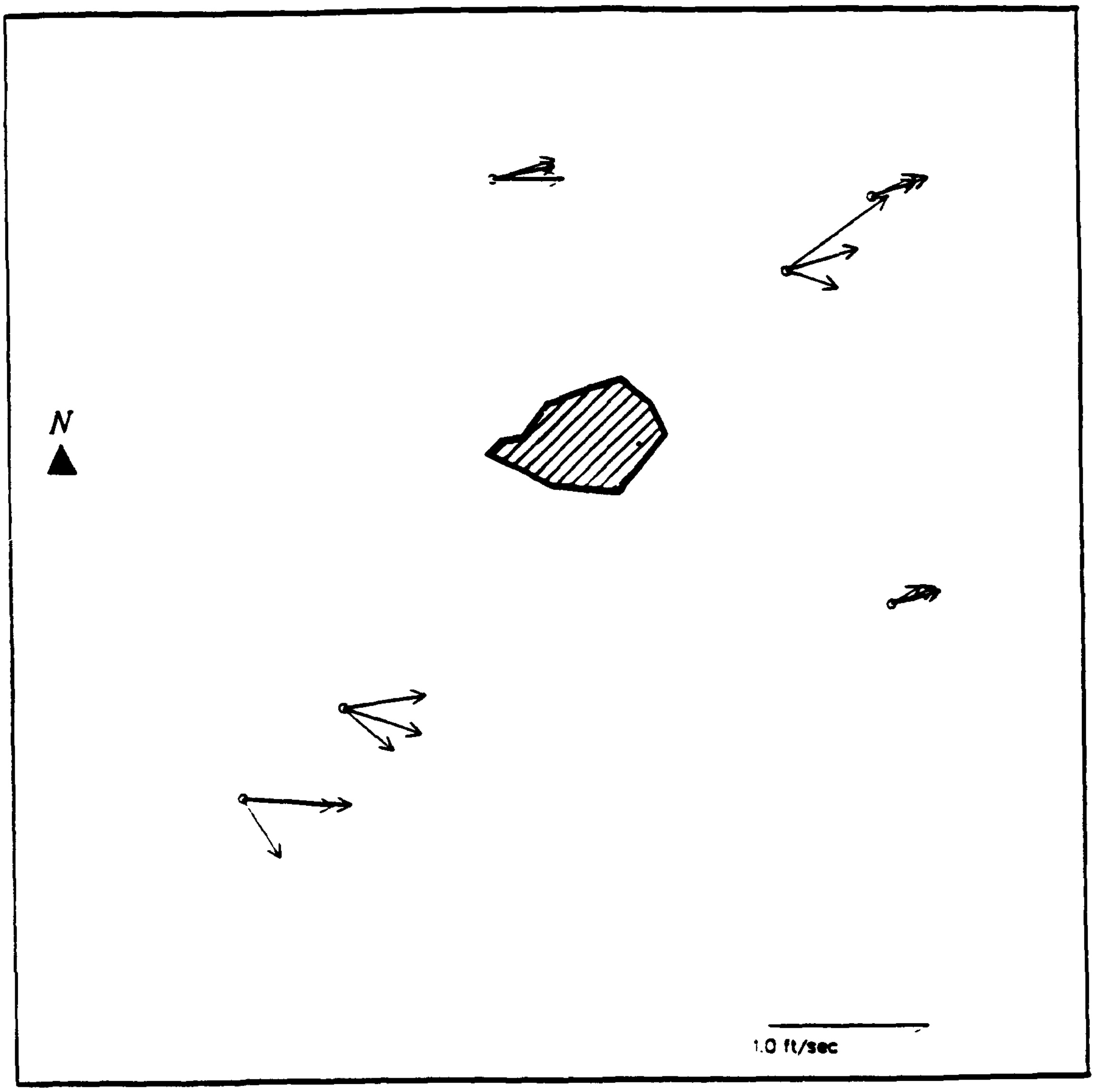


Figure 43. Velocity vectors, 08:59 to 09:18 EST, 8 June 1991

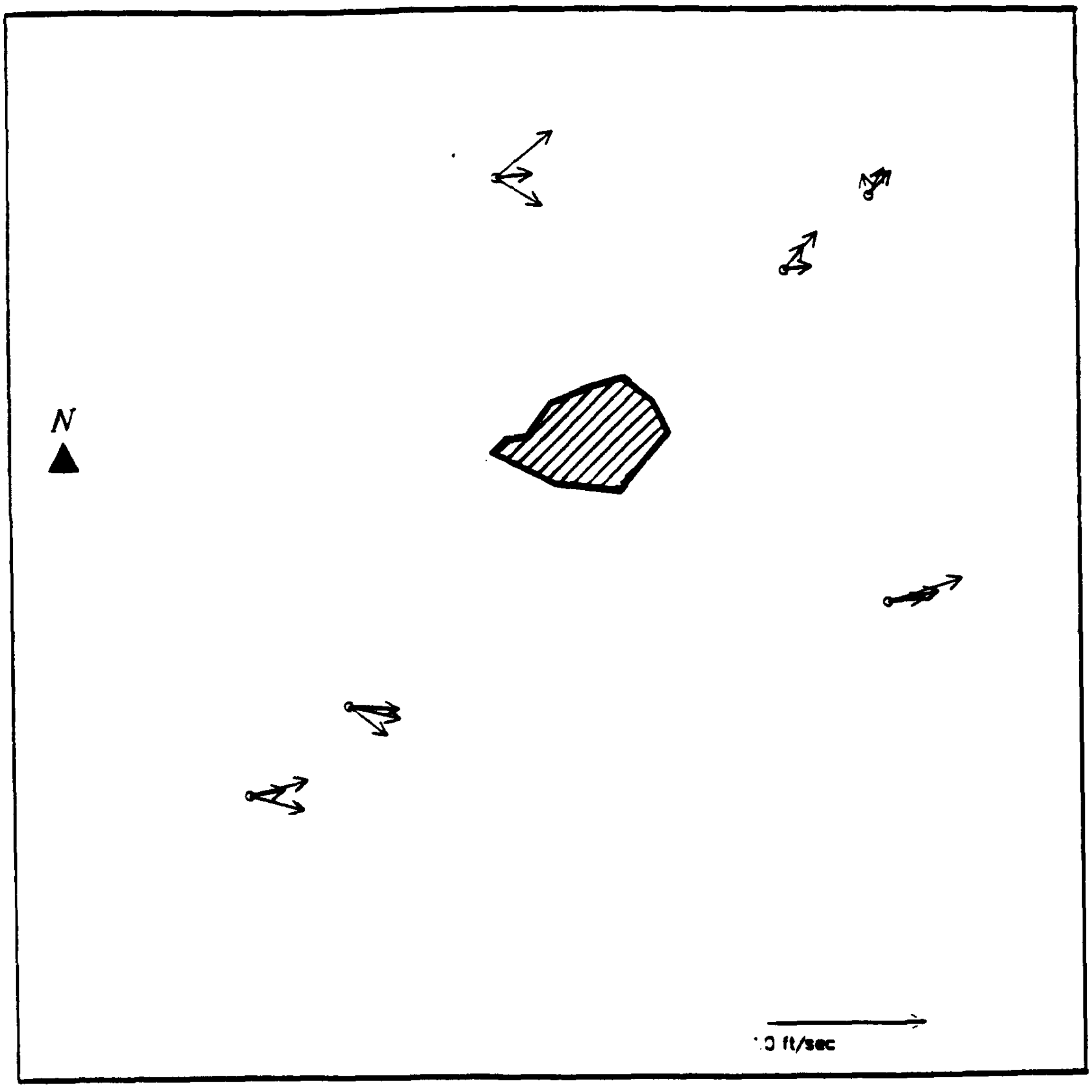


Figure 44. Velocity vectors, 10:03 to 10:19 EST, 8 June 1991

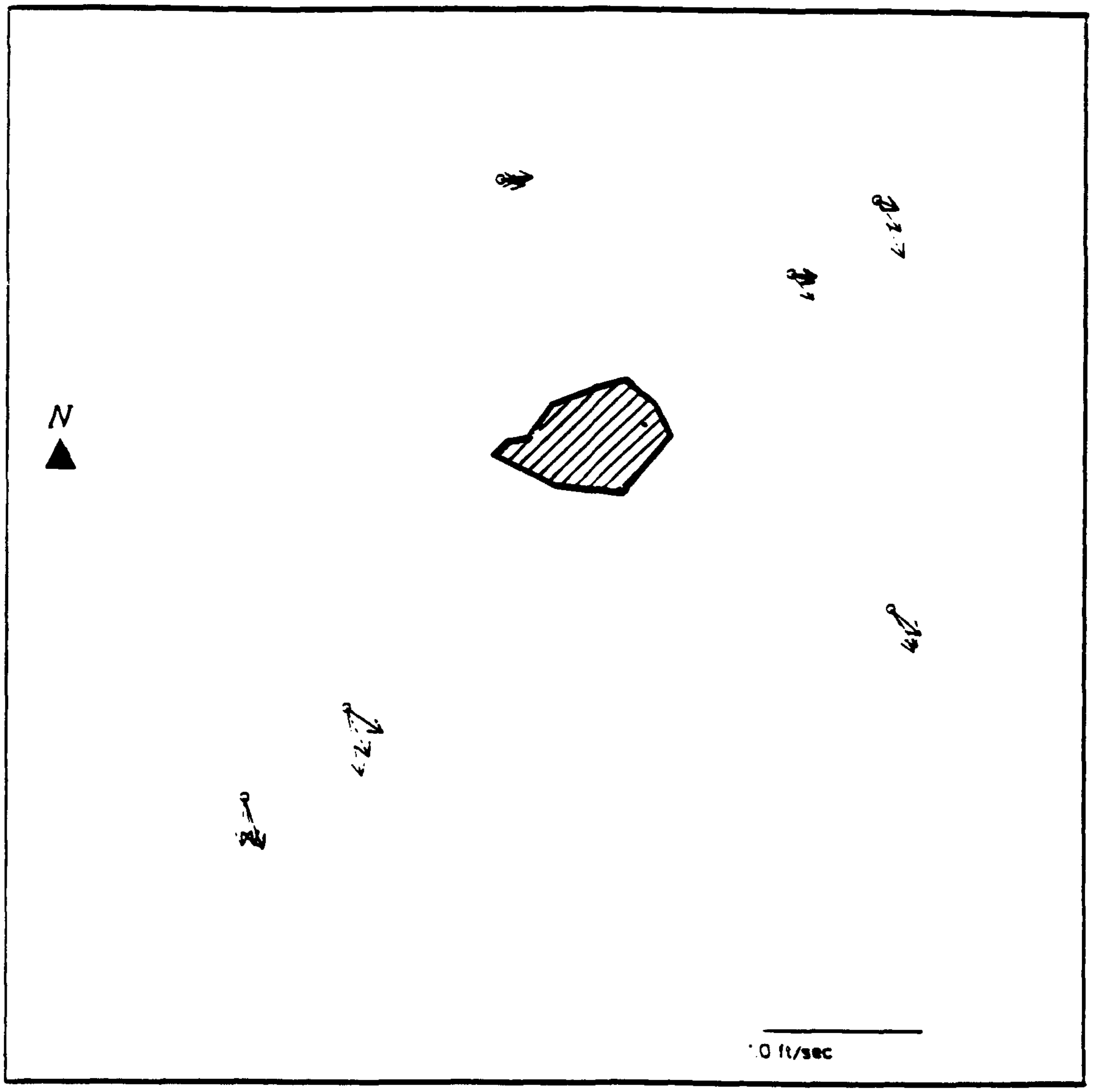


Figure 45. Velocity vectors, 11:00 to 11:15 EST, 8 June 1991

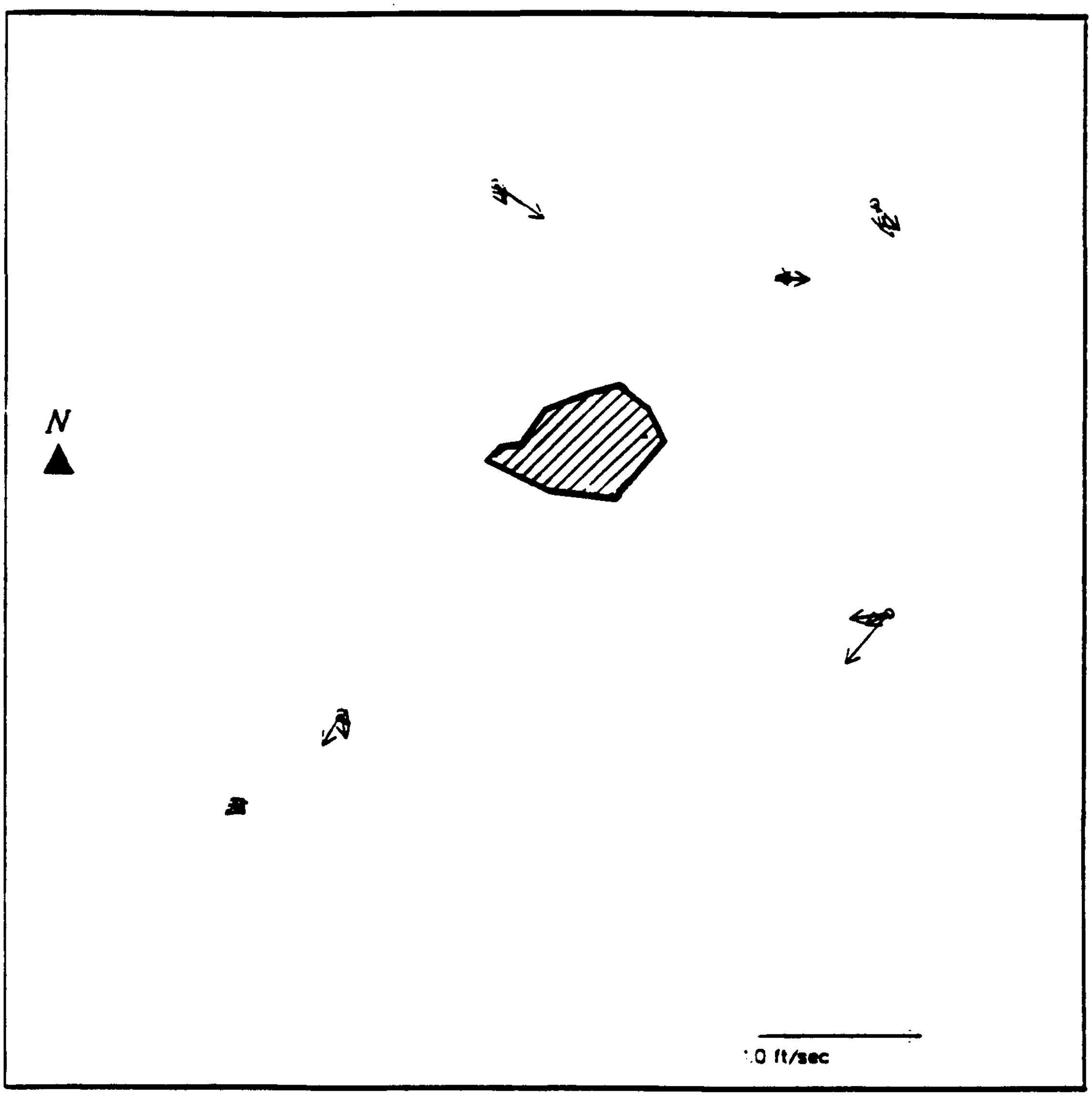


Figure ?. Velocity vectors, 12:00 to 12:18 EST, 8 June 1991

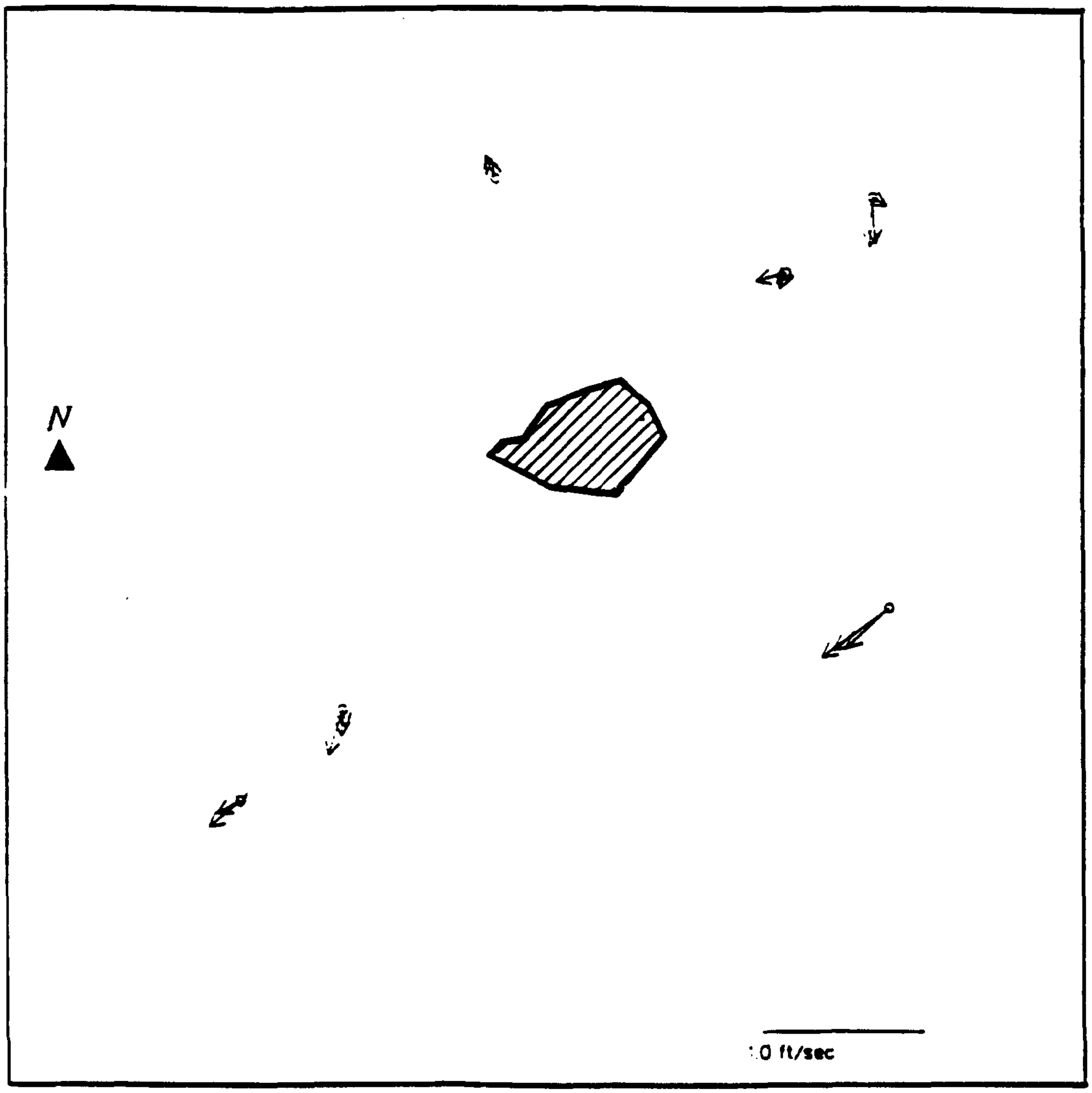


Figure 47. Velocity vectors, 13:00 to 13:14 EST, 8 June 1991

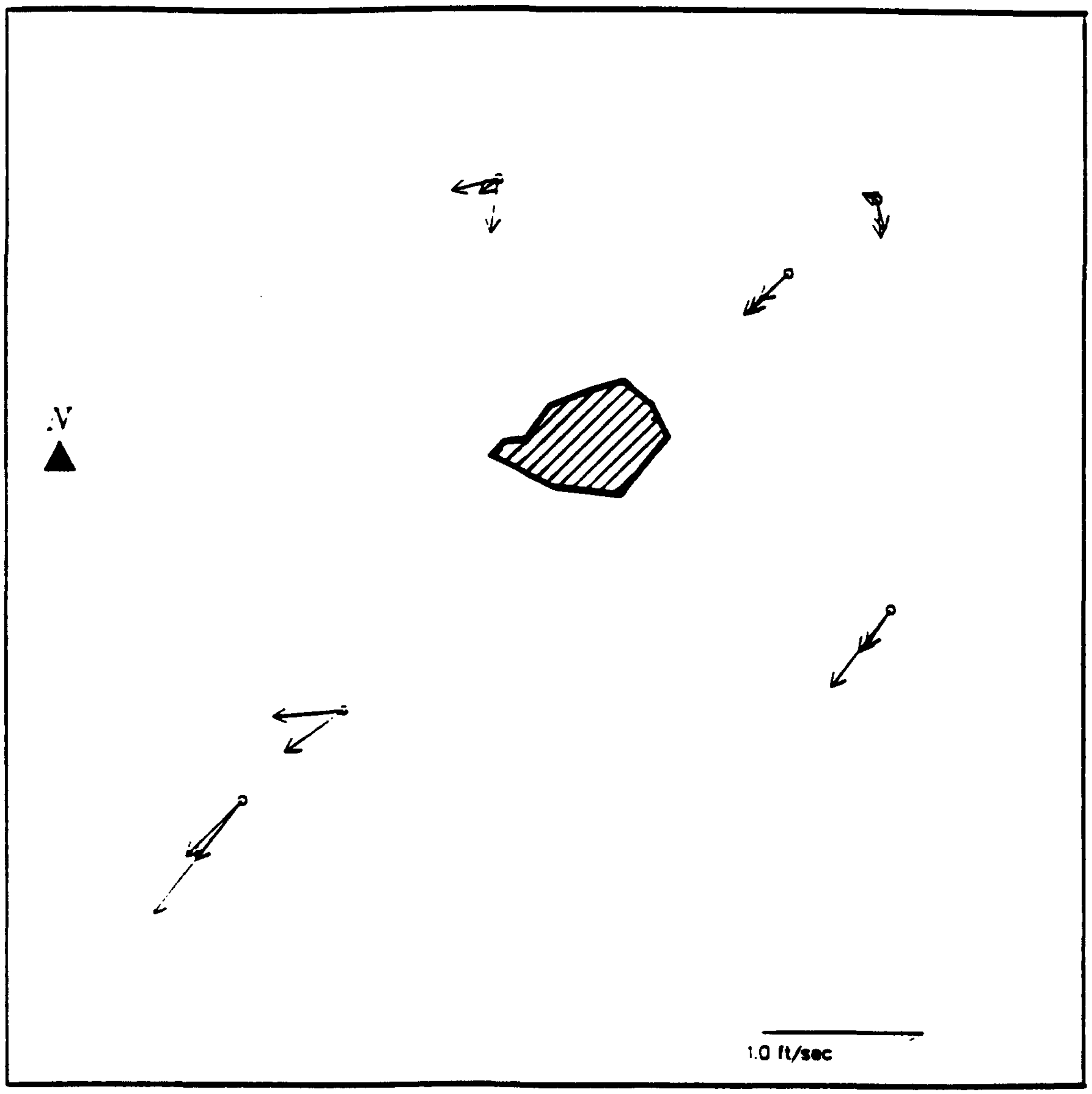


Figure 48. Velocity vectors, 14:00 to 14:15 EST, 8 June 1991

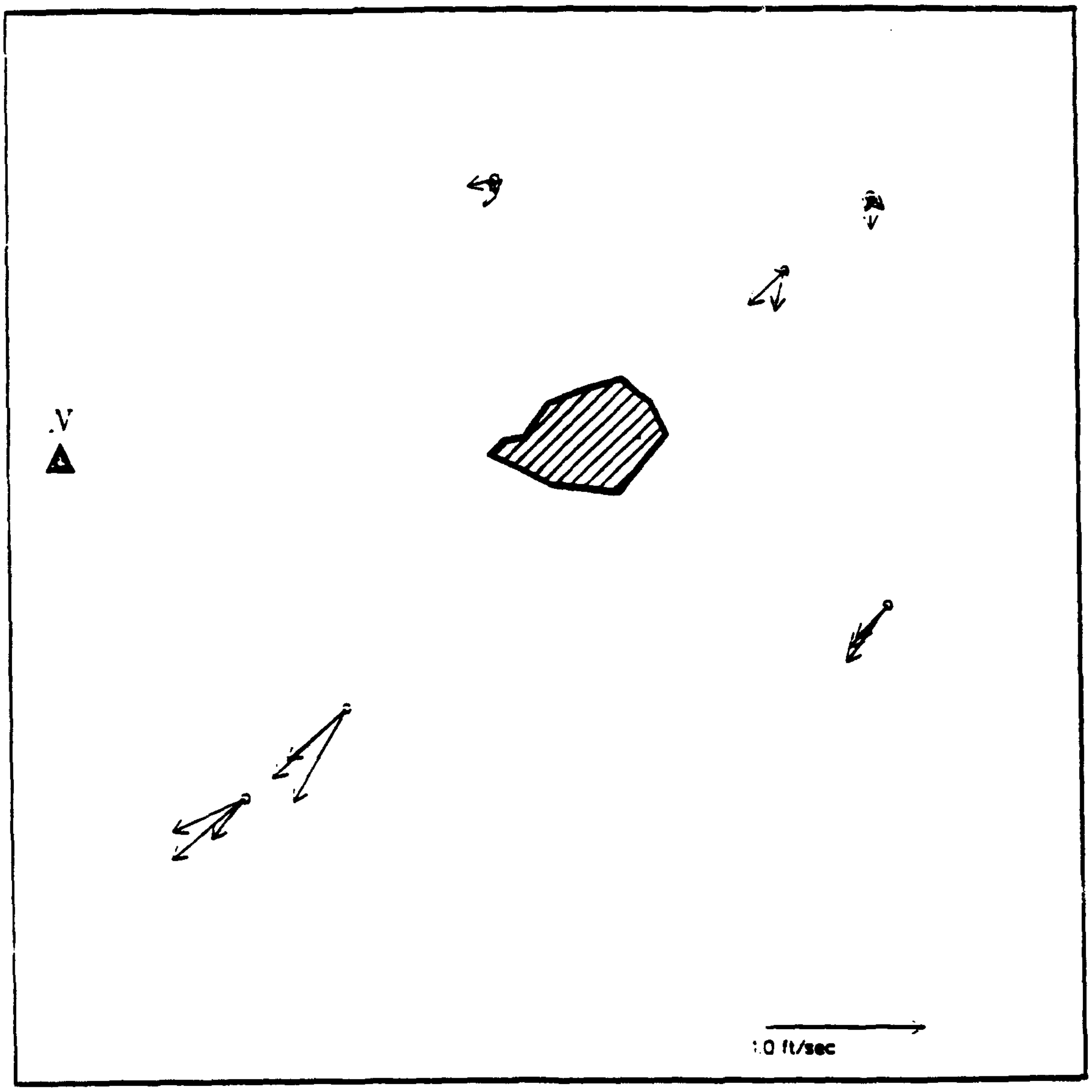


Figure 49. Velocity vectors, 15:02 to 15:18 EST, 8 June 1991

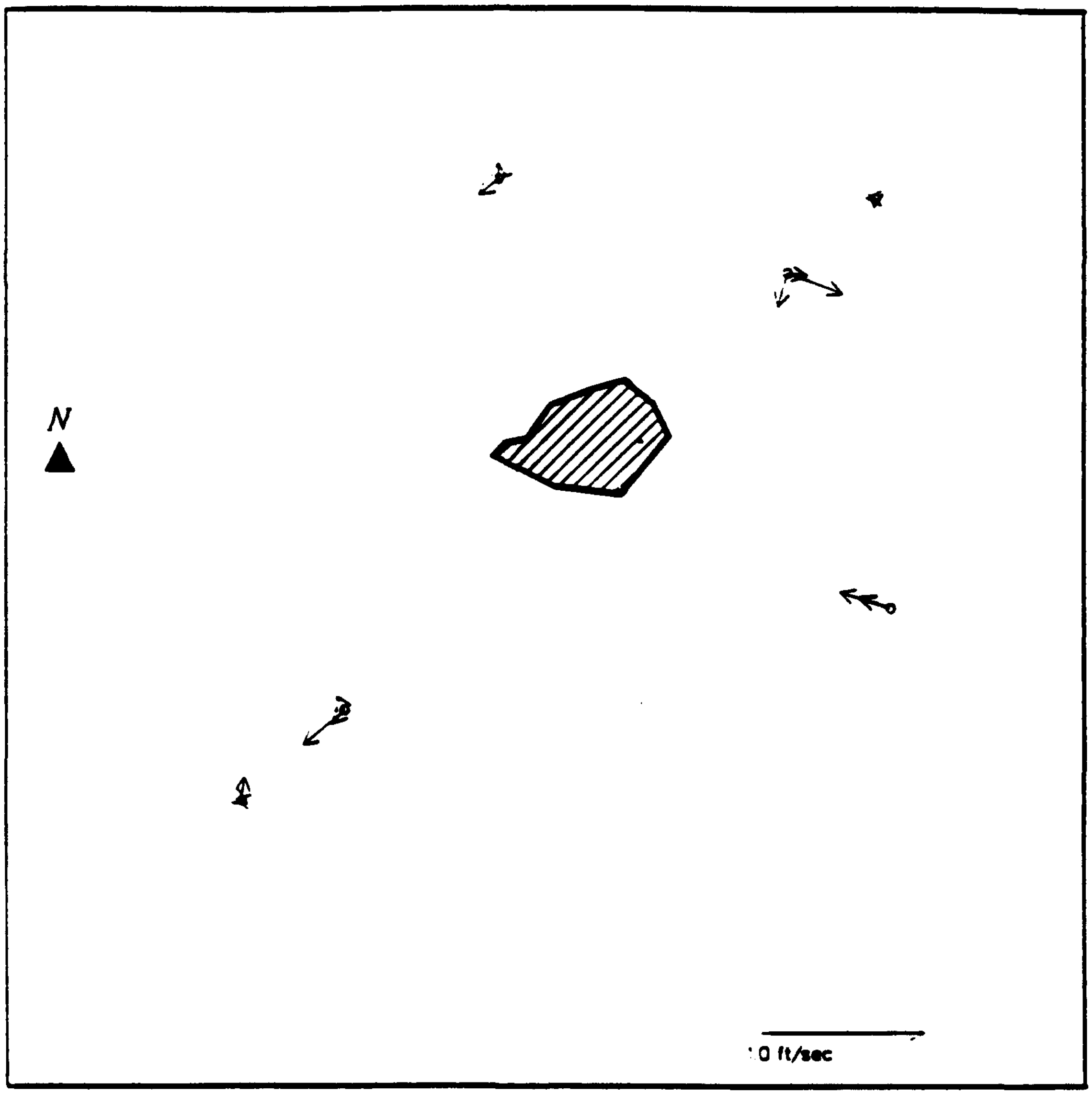


Figure 50. Velocity vectors, 16:00 to 16:15 EST, 8 June 1991

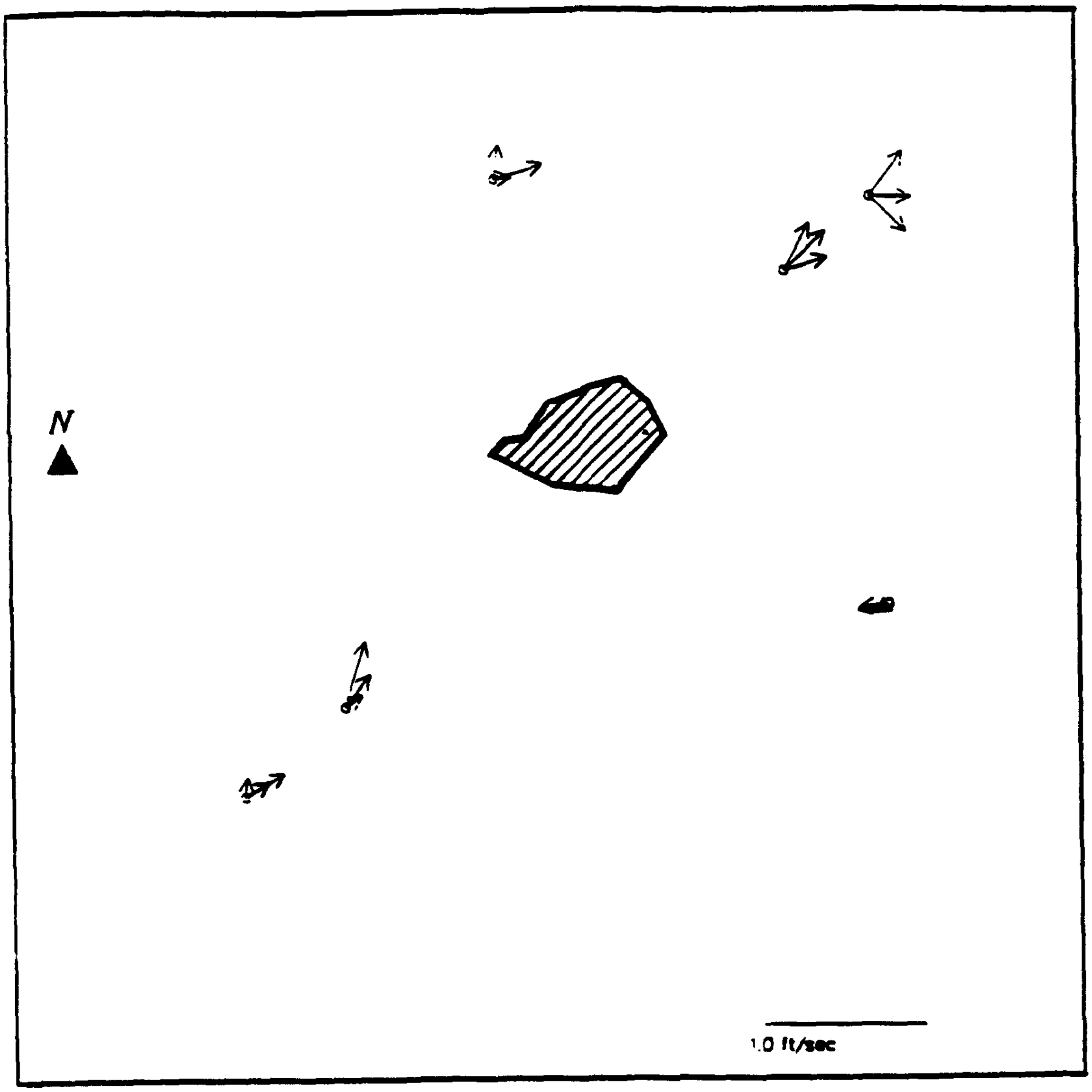


Figure 51. Velocity vectors, 17:00 to 17:20 EST, 8 June 1991

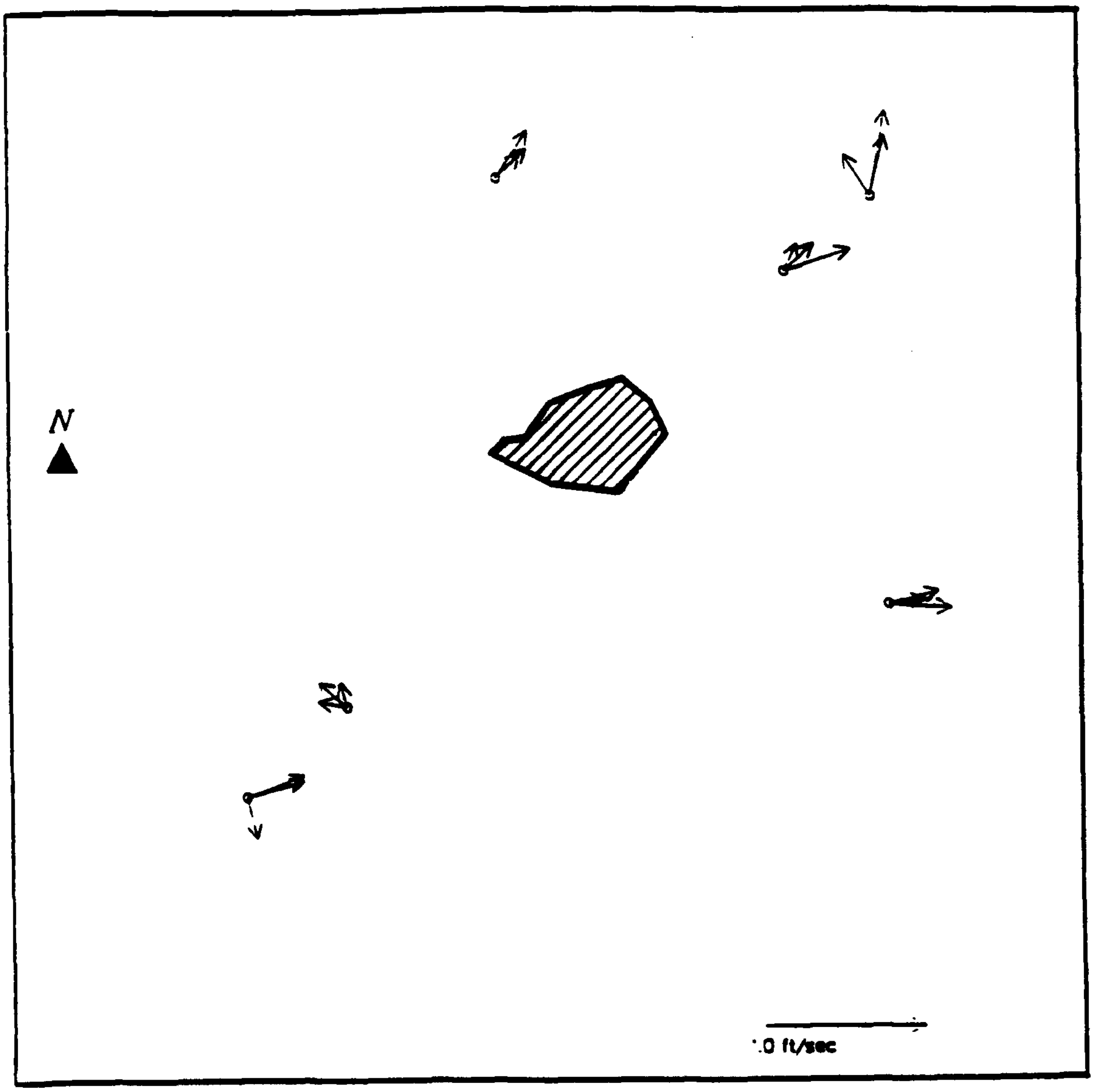


Figure 52. Velocity vectors, 18:00 to 18:21 EST, 8 June 1991

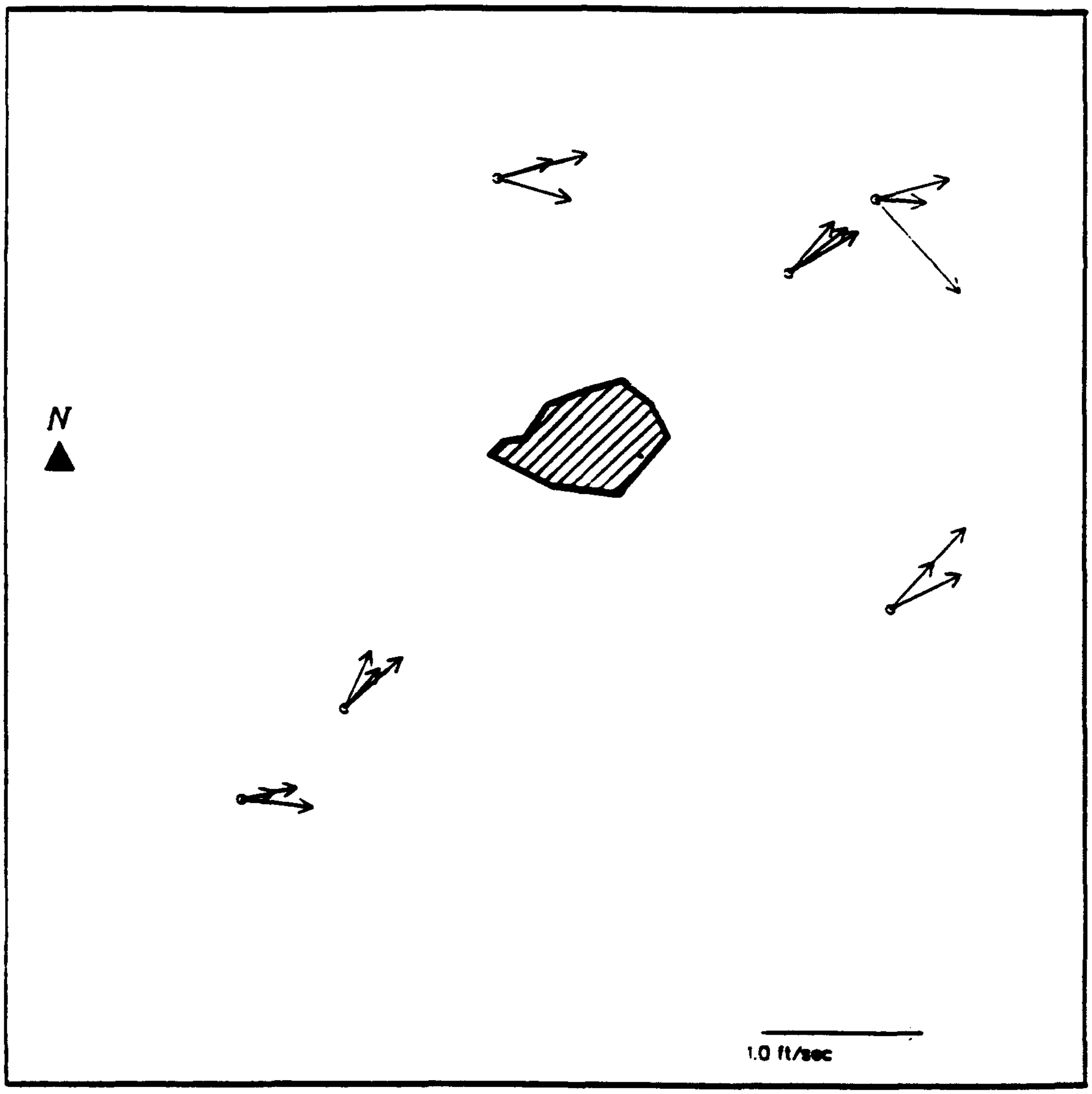


Figure 53. Velocity vectors, 18:28 to 18:53 EST, 8 June 1991

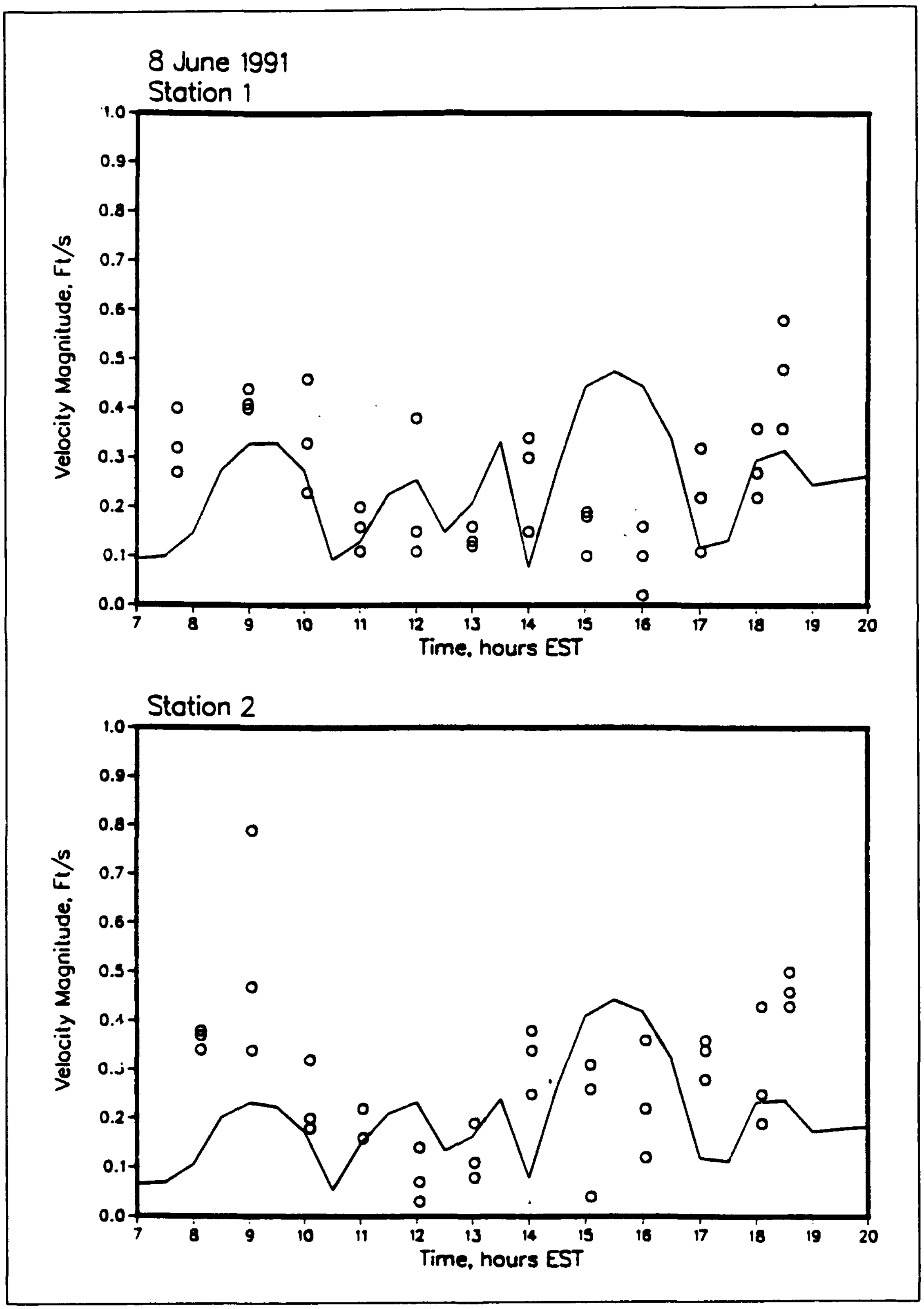


Figure 54. Velocity magnitudes, prototype (o) versus Model (—), stations 1 and 2

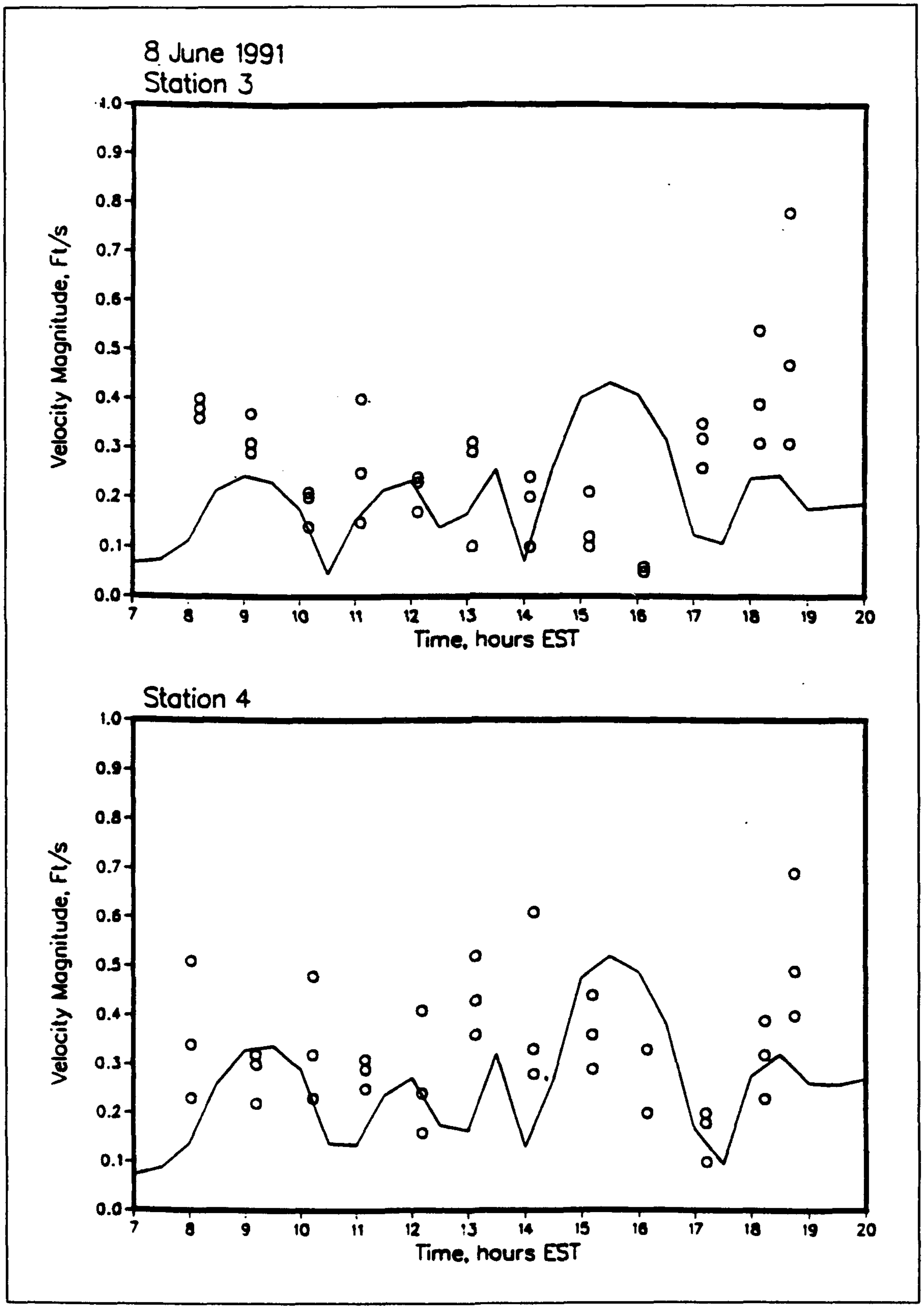


Figure 55. Velocity magnitudes, prototype (o) versus Model (—), stations 3 and 4

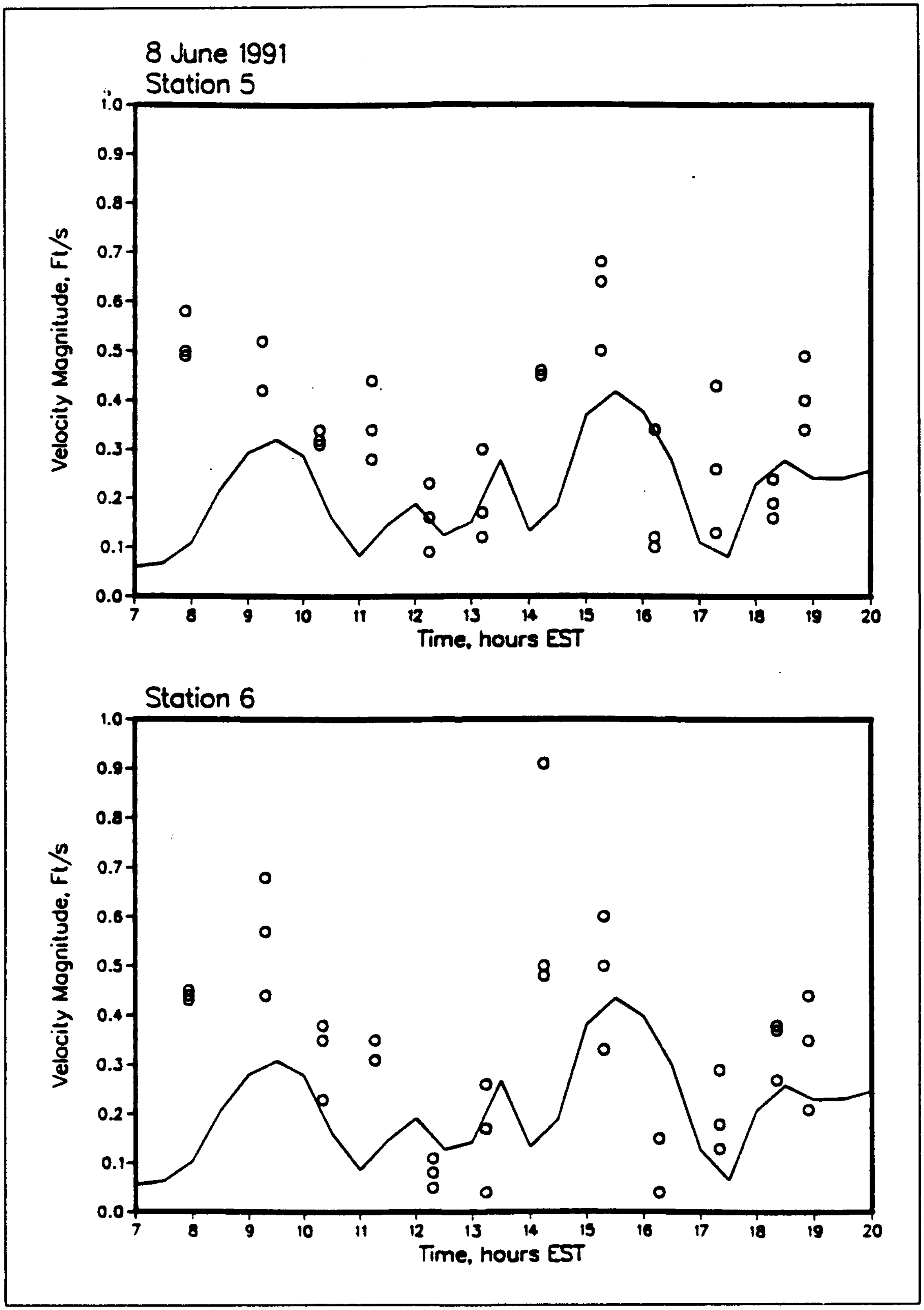


Figure 56. Velocity magnitudes, prototype (o) versus Model (—), stations 5 and 6

Table 1
Summary of Stone and Geotextile Quantity Estimates

Section Description	Azimuth Range °TN	Perimeter Length ft	Armor Stone			Rock Spalls		Geotextile	
			W_{50} lb	Mass tons/ft	Total tons	Mass tons/ft	Total tons	Area yd^2/ft	Total yd^2
Southeast Section	100-140	185	800	6.184	1144	18.99	3513	12.0	2220
Bulkhead Only	140-167	130	800	6.184	804	11.39	1481	9.5	1228
Existing Riprap	167-221	275	800	1.091	300	4.75	1306	5.6	1528
Southwest	221-300	370	800	6.184	2288	18.99	7026	12.0	4440
Transition	300-304	20	800	5.270	106	16.80	336	11.3	226
Northwest	304-341	190	360	4.365	829	14.58	2770	10.6	2006
Sill	327-33	200	100	6.085	1217	—	1385	8.4	1667
Northeast	19-96	375	360	4.365	1637	14.58	5466	10.6	3958
Transition	96-100	20	800	5.270	105	16.80	335	11.3	225
					$\Sigma = 8430$		$\Sigma = 23618$		$\Sigma = 17498$

Table 2
Armor Stone Volumes/Tonnage[1]

Section	Perimeter Length ft	W_{50} lb	Thickness[2] r ft	X-Sect Area ft^2	Volume Req'd[3,4] yd^2	Tons Req'd tons
North Sections d = 3.0 ft	565	360	2.75	81.4	1703	2466
South Sections d = 3.5 ft	685	800	3.5	115.3	2926	4236
Transitions	40	800	3.125	98.4	146	211
Existing Riprap	275	800	3.5	19.6	200	300
Sill						
1:6 Slope	240	100	2.0	36	320	463
Flat	175	100	2.0	70	454	657
1:2 Slope	150	100	2.0	12	67	97
						$\Sigma = 8430$

[1] Refer to Figure 18 (Riprap Plan).
[2] Sill structure armor layer thickness, $r = 2\,(W_{50}/W_r) = 1.7$ ft = 2.0 ft.
[3] Porosity assumed to be 35 percent.
[4] Channel reduces volume requirements, but is relatively small percentage.

Table 3
Rock Spall Volumes/Tonnage for Containment Dike[1,2,3]

Section	Perimeter Length ft	X-Sect Area[4] ft	Volume Req'd[5] yd^3	Tons Req'd[6] tons
North Sections	660	228	5573	9621
South Sections	555	297	6105	10539
Transitions	40	262.5	389	671
Bulkhead Only	130	178.2	858	1481
Exist. Riprap	275	74.25	756	1306
Totals	$\Sigma = 1660$ ft		$\Sigma = 13681\ yd^3$	$\Sigma = 23618$ tons

[1] Refer to Figure 8 (Rock Spall Containment Dike).
[2] Additionl rock spalls to be used at toe protection layer of 1-ft thickness approximately 6.5 ft long covering 1385 ft of perimeter would require 360 yd^3 or 620 tons.
[3] Rock spalls may be used in splash apron depending on their size. Apron is to extend to +10 ft MLW.
[4] One foot of settlement/displacement considered.
[5] Porosity, P, of rock spalls = 22.5 percent.
[6] Unit weight of rock spalls = 165 lb/ft^3.

Table 4
Geotextile Requirements[1]

Section	Perimenter Length ft	Length per Cross-section		Total Yardage yd^2
		Foundation[2] ft	Fill[3] ft	
North Sections	565	60	35	5964
South Sections	555	70	38	6660
Transitions	40	65	365	451
Bulkhead Only	130	60	25	1228
Exist. Riprap	275	25	25	1528
Sill	200	75	—	1667
				$\Sigma = 17489\ yd^2$

[1] Refer to Figure 18 (Riprap Plan) and Figure 8 (Rock Spall Containment Dike).
[2] Geotextile placed beneath rock spalls.
[3] Geotextile on the island side of the rock spall containment dike.

Table 5
Bodkin Island Survey Data, 8 June 1991

Time EST	Speed ft/sec	Direction True North
Station 1 Field Data		
7:43	0.27	285.0°
7:43	0.32	329.0°
7:43	0.40	334.0°
8:59	0.44	270.0°
8:59	0.41	253.0°
8:59	0.40	258.0°
10:03	0.46	230.0°
10:03	0.23	262.0°
10:03	0.33	301.0°
11:00	0.16	284.0°
11:00	0.11	275.0°
11:00	0.20	266.0°
12:00	0.38	305.0°
12:00	0.15	329.0°
12:00	0.11	314.0°
13:00	0.16	157.0°
13:00	0.12	169.0°
13:00	0.13	157.0°
14:00	0.15	51.0°
14:00	0.30	76.0°
14:00	0.34	8.0°
15:02	0.10	356.0°
15:02	0.18	74.0°
15:02	0.19	21.0°
16:00	0.02	37.0°
16:00	0.16	52.0°
16:00	0.10	176.0°
17:01	0.22	188.0°
17:01	0.11	262.0°
17:01	0.32	253.0°

(Sheet 1 of 8)

Table 5 (Continued)		
Time EST	**Speed ft/sec**	**Direction True North**
Station 1 Field Data (Concluded)		
18:01	0.27	225.0°
18:01	0.36	213.0°
18:01	0.22	224.0°
18:28	0.48	286.0°
18:28	0.58	255.0°
18:28	0.36	252.0°
Station 2 Field Data		
8:08	0.34	138.0°
8:08	0.37	105.0°
8:08	0.38	77.0°
9:03	0.34	288.0°
9:03	0.79	234.0°
9:03	0.47	253.0°
10:06	0.18	262.0°
10:06	0.32	222.0°
10:06	0.20	218.0°
11:03	0.22	319.0°
11:03	0.16	277.0°
11:03	0.16	289.0°
12:03	0.07	99.0°
12:03	0.14	273.0°
12:03	0.03	299.0°
13:02	0.08	40.0°
13:02	0.11	20.0°
13:02	0.19	74.0°
14:03	0.38	47.0°
14:03	0.25	47.0°
14:03	0.34	45.0°
15:06	0.04	321.0°
15:06	0.31	47.0°

(Sheet 2 of 8)

Table 5 (Continued)		
Time EST	**Speed ft/sec**	**Direction True North**
Station 2 Field Data (Concluded)		
15:06	0.26	13.0°
16:03	0.22	16.0°
16:03	0.36	291.0°
16:03	0.12	278.0°
17:06	0.28	253.0°
17:06	0.36	227.0°
17:06	0.34	209.0°
18:06	0.25	227.0°
18:06	0.19	204.0°
18:06	0.43	252.0°
18:36	0.50	239.0°
18:36	0.46	232.0°
18:36	0.43	221.0°
Station 3 Field Data		
8:12	0.40	118.0°
8:12	0.36	123.0°
8:12	0.38	98.0°
9:07	0.37	251.0°
9:07	0.29	252.0°
9:07	0.31	245.0°
10:09	0.14	164.0°
10:09	0.20	209.0°
10:09	0.21	222.0°
11:06	0.25	322.0°
11:06	0.15	293.0°
11:06	0.40	335.0°
12:07	0.17	343.0°
12:07	0.23	317.0°
12:07	0.24	330.0°
13:05	0.31	4.0°

(Sheet 3 of 8)

Table 5 (Continued)		
Time EST	Speed ft/sec	Direction True North
Station 3 Field Data (Concluded)		
13:05	0.10	302.0°
13:05	0.29	357.0°
14:06	0.10	110.0°
14:06	0.20	346.0°
14:06	0.24	354.0°
15:09	0.12	314.0°
15:09	0.21	359.0°
15:09	0.10	15.0°
16:06	0.05	89.0°
16:06	0.06	5.0°
16:06	0.05	322.0°
17:09	0.26	271.0°
17:09	0.35	216.0°
17:09	0.32	314.0°
18:09	0.31	147.0°
18:09	0.39	193.0°
18:09	0.54	190.0°
18:40	0.47	254.0°
18:40	0.78	318.0°
18:40	0.31	274.0°
Station 4 Field Data		
8:02	0.23	286.0°
8:02	0.34	231.0°
8:02	0.51	223.0°
9:12	0.30	249.0°
9.12	0.32	255.0°
9:12	0.22	239.0°
10:13	0.48	252.0°
10:13	0.23	264.0°
10:13	0.32	258.0°
		(Sheet 4 of 8)

Table 5 (Continued)		
Time EST	**Speed ft/sec**	**Direction True North**
	Station 4 Field Data (Concluded)	
11:10	0.31	332.0°
11:10	0.29	325.0°
11:10	0.25	311.0°
12:11	0.41	40.0°
12:11	0.24	82.0°
12:11	0.16	62.0°
13:08	0.52	54.0°
13:08	0.36	47.0°
13:08	0.43	53.0°
14:09	0.61	37.0°
14:09	0.33	37.0°
14:09	0.28	33.0°
15:12	0.44	36.0°
15:12	0.36	43.0°
15:12	0.29	44.0°
16:09	0.33	108.0°
16:09	0.20	107.0°
16:09	0.20	111.0°
17:12	0.20	76.0°
17:12	0.18	82.0°
17:12	0.10	57.0°
18:14	0.32	255.0°
18:14	0.23	262.0°
18:14	0.39	274.0°
18:45	0.49	243.0°
18:45	0.69	222.0°
18:45	0.40	222.0°

(Sheet 5 of 8)

Table 5 (Continued)		
Time EST	Speed ft/sec	Direction True North
	Station 5 Field Data	
7:53	0.58	287.0°
7:53	0.50	298.0°
7:53	0.49	295.0°
9:15	0.42	311.0°
9:15	0.52	289.0°
9:15	0.52	262.0°
10:17	0.31	307.0°
10:17	0.32	274.0°
10:17	0.34	284.0°
11:13	0.34	334.0°
11:13	0.44	347.0°
11:13	0.28	304.0°
12:15	0.23	30.0°
12:15	0.09	325.0°
12:15	0.16	347.0°
13:11	0.30	18.0°
13:11	0.17	3.0°
13:11	0.12	349.0°
14:12	0.45	85.0°
14:12	0.46	55.0°
14:12	0.45	55.0°
15:15	0.68	30.0°
15:15	0.64	47.0°
15:15	0.50	49.0°
16:12	0.34	50.0°
16:12	0.10	150.0°
16:12	0.12	43.0°
17:17	0.26	218.0°
17:17	0.13	233.0°
17:17	0.43	197.0°
		(Sheet 6 of 8)

Table 5 (Continued)		
Time EST	Speed ft/sec	Direction True North
Station 5 Field Data (Concluded)		
18:18	0.19	102.0°
18:18	0.16	165.0°
18:18	0.24	131.0°
18:51	0.34	222.0°
18:51	0.40	205.0°
18:51	0.49	229.0°
Station 6 Field Data		
7:56	0.45	272.0°
7:56	0.43	272.0°
7:56	0.44	275.0°
9:18	0.44	328.0°
9:18	0.68	274.0°
9:18	0.57	275.0°
10:20	0.38	255.0°
10:20	0.23	259.0°
10:20	0.35	285.0°
11:16	0.35	341.0°
11:16	0.31	348.0°
11:16	0.31	3.0°
12:18	0.08	332.0°
12:18	0.05	138.0°
12:18	0.11	49.0°
13:14	0.26	50.0°
13:14	0.04	1.0°
13:14	0.17	61.0°
14:15	0.91	38.0°
14:15	0.50	45.0°
		(Sheet 7 of 8)

Table 5 (Concluded)		
Time EST	**Speed ft/sec**	**Direction True North**
Station 6 Field Data (Concluded)		
14:15	0.48	38.0°
15:18	0.60	50.0°
15:18	0.50	65.0°
15:18	0.33	39.0°
16:16	0.04	301.0°
16:16	0.04	100.0°
16:16	0.15	187.0°
17:20	0.29	239.0°
17:20	0.18	239.0°
17:20	0.13	187.0°
18:21	0.27	346.0°
18:21	0.37	254.0°
18:21	0.38	249.0°
18:54	0.44	277.0°
18:54	0.35	258.0°
18:54	0.21	258.0°
		(Sheet 8 of 8)

Table 6
Plant Material Required for Complete Planting of Bodkin Island with Sprigs and Potted Shrubs[1]

Habitats	Estimated ft^2	Elevational Limits ft	Estimated No. of Sprigs/Plants
Crest/Upper Slope (1.22 acres new upland)			
Black cherry (5-plant clusters on 6-ft centers/100 ft)	3,888	+4.0 - +10.0	650
Japanese honeysuckle (3-ft centers)	13,196	+4.0 - +10.0	4,398
Poison ivy (3-ft centers)	13,196	+4.0 - +10.0	4,398
Saltmeadow cordgrass (1 sprig/4th center)	9,056	+1.0 - +9.0	3,018
High Marsh Zone (0.35 acres)			
Marsh elder (plant clusters on 3-ft centers)	1,378	+2.0 - +4.0	459
Saltgrass (mixed planting with saltmeadow cord-grass, 3-ft centers)	2,755	+1.0 - +4.0	918
Saltmeadow cordgrass (mixed planting with saltgrass, 3-ft centers)	8,265	+1.0 - +10.0	2,755
Saltmarsh bulrush (mixed planting at MLHT with other species, 3-ft centers)	2,066	+1.0 - +2.0	688
Olney's threesquare (mixed planting at MLHT with other species, 3-ft centers)	2,066	+1.0 - +2.0	688
Low Marsh Zone (1.37 acres)			
Smooth cordgrass (sprigs on 3-ft centers)	59,677	-1.0 - +1.0	20,445
Tidal Pools[2] (0.63 acres)			
Widgeongrass	14,355	-3.0 - -1.0	4,785
Horned pondweed	4,785	-3.0 - -1.0	1,595
Redhead grass	4,785	-3.0 - -1.0	1,595
Sago pondweed	4,785	-3.0 —1.0	1,595

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Bodkin Island in the Chesapeake Bay is considered prime habitat for nesting black ducks; however, wind wave erosion is threatening the continued existence of the island. The existing 1-acre island will be increased by 4.8 acres through placement of dredged material to create nesting and brood habitat for black ducks. The enlarged island will have uplands, and high and low marshes with intertidal channels and pools with submerged aquatic vegetation. Riprap will be placed around the perimeter of the island to prevent wind wave erosion. The interdisciplinary project design report includes hydraulic and wave-climate numerical model studies, island design, habitat shaping, and vegetation selection.

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